Communicating with Astronaut and Robotic Explorers Across the Universe

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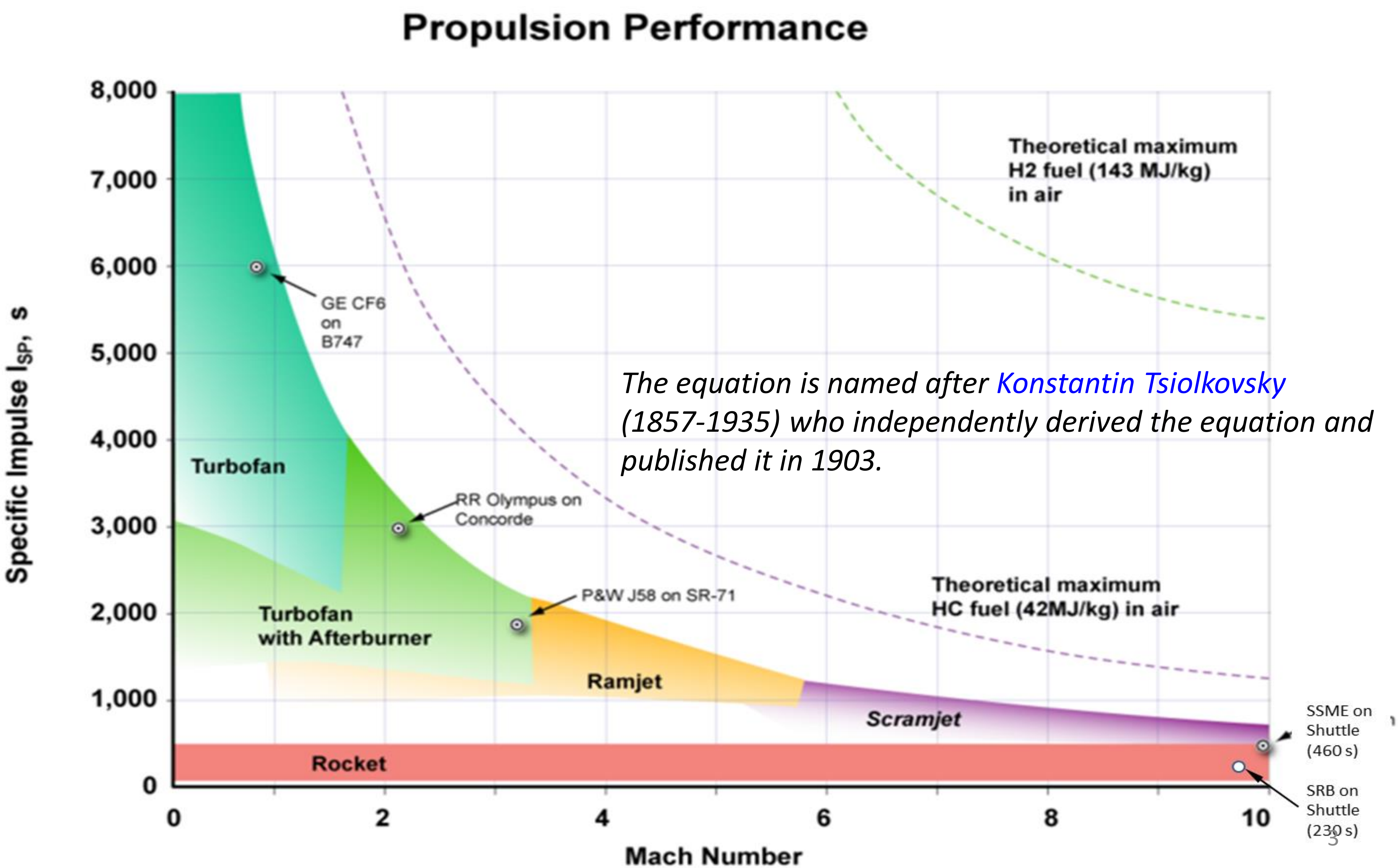
Rocket Science
The Start of Every Space Mission

Rocket Equation



The equation is named after Konstantin Tsiolkovsky (1857-1935) who independently derived the equation and published it in 1903.

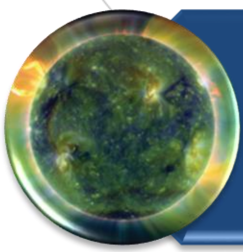
National Aeronautics and Space Administration (NASA)

Aeronautics

Manages research focused on meeting global demand for air mobility in ways that are more environmentally friendly and sustainable, while also embracing revolutionary technology from outside aviation

Human Exploration and Operations

Focuses on International Space Station operations, development of commercial spaceflight capabilities and human exploration beyond low-Earth orbit.



Science

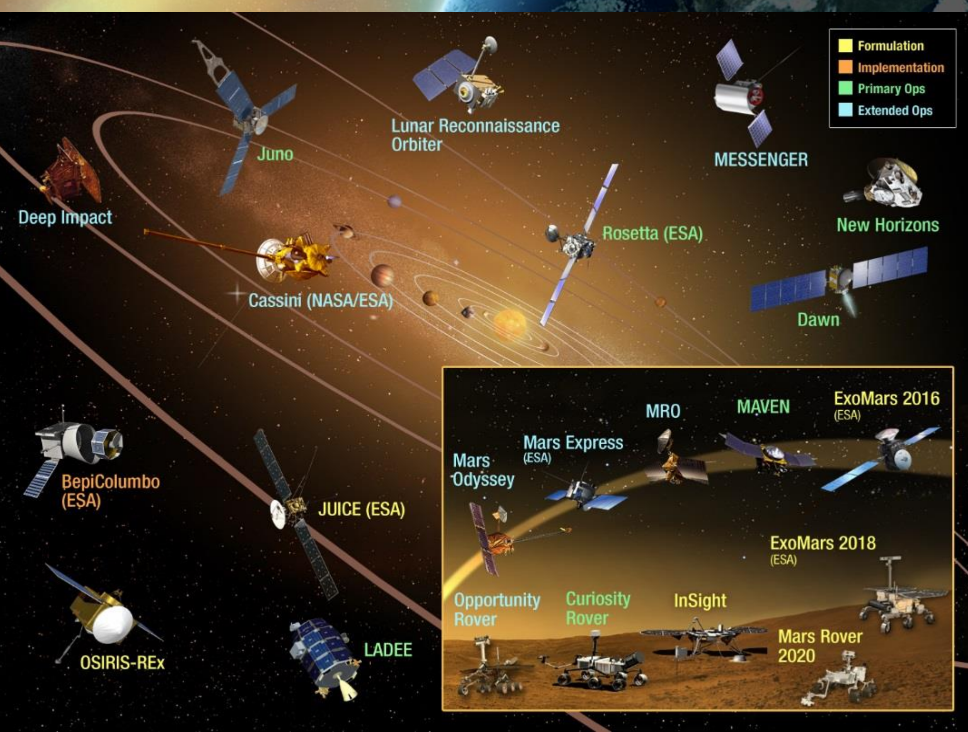
Explores the Earth, solar system and universe beyond; charts the best route of discovery; and reaps the benefits of Earth and space exploration for society.

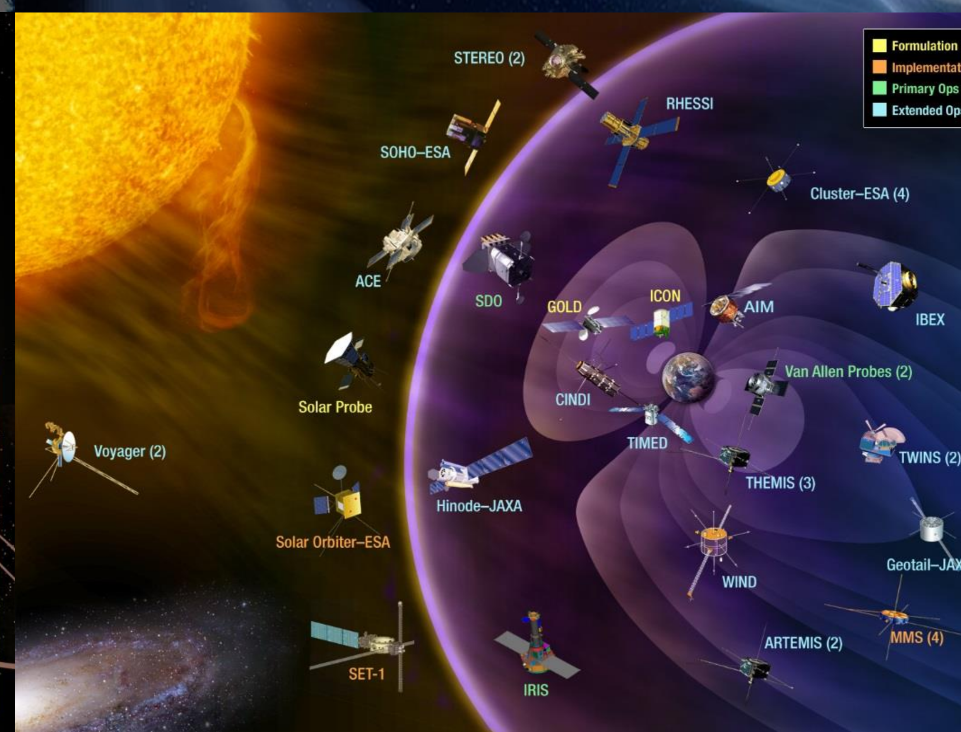
Space Technology

Rapidly develops, innovates, demonstrates, and infuses revolutionary, high-payoff technologies that enable NASA's future missions while providing economic benefit to the nation.

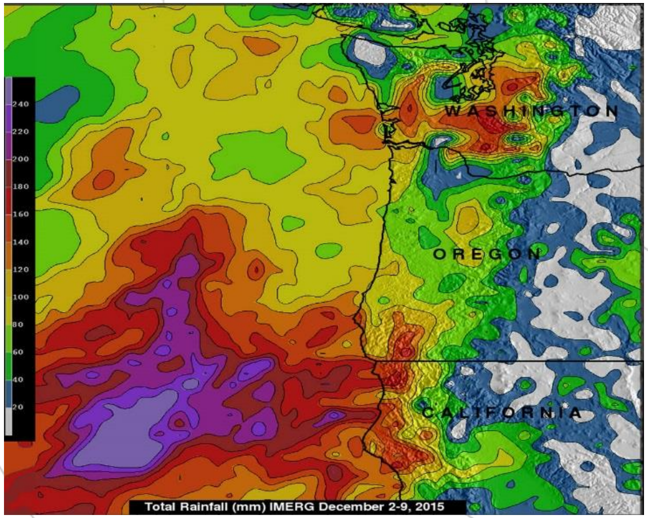

Formulation
Implementation
Primary Ops
Extended Ops
XMM-Newton (ESA)
12/10/1999
Swift
11/20/2004
Suzaku (JAXA)
7/10/2005
Fermi
6/11/2008
Euclid (ESA)
2020
Spitzer
8/25/2003
Hubble
4/24/1990
Kepler
3/6/2009
Astro-H (JAXA)
2015
JWST
2018
Chandra
7/23/1999
NICER (on ISS)
2016
NuSTAR
6/13/2012
TESS
2017
LISA Pathfinder (ESA)
2015
SOFIA
Full Ops 2014

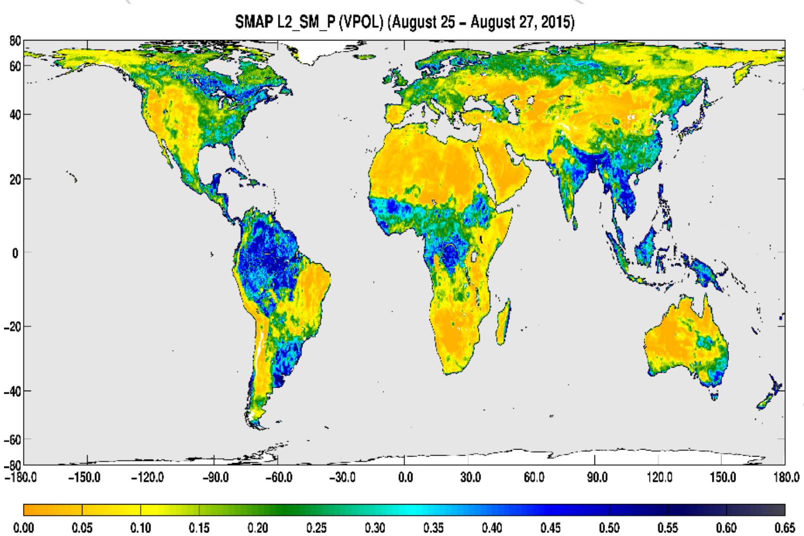

RapidSCAT (ISS)
SMAP
CATS (ISS)
OCO-2
GPM
Landsat 8
(USGS)
Suomi NPP
Aquarius
OSTM/Jason 2
CALIPSO
CloudSat
Aura
SORCE
Aqua
GRACE (2)
Terra
EO-1
QuikSCAT
TRMM
Landsat 7 (USGS)


Formulation
Implementation
Primary Ops
Extended Ops
Lunar Reconnaissance
Orbiter
Juno
MESSENGER
Deep Impact
New Horizons
Rosetta (ESA)
Cassini (NASA/ESA)
Dawn
MRO
MAVEN
ExoMars 2016
(ESA)
Mars Express
(ESA)
Mars
Odyssey
BepiColumbo
(ESA)
JUICE (ESA)
ExoMars 2018
(ESA)
Opportunity
Rover
Curiosity
Rover
InSight
Mars Rover
2020
OSIRIS-REx
LADEE


Formulation
Implementat
Primary Ops
Extended Op
STEREO (2)
RHESSI
SOHO–ESA
Cluster–ESA (4)
ACE
SDO
GOLD
ICON
AIM
IBEX
Van Allen Probes (2)
CINDI
Solar Probe
TIMED
Voyager (2)
TWINS (2)
THEMIS (3)
Hinode–JAXA
Solar Orbiter–ESA
Geotail–JAX
WIND
ARTEMIS (2)
MMS (4)
SET-1
IRIS

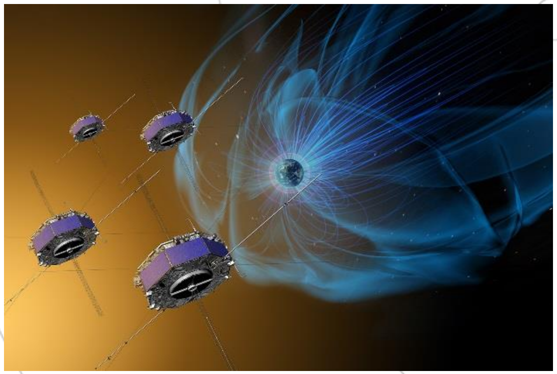
Earth Observing Missions

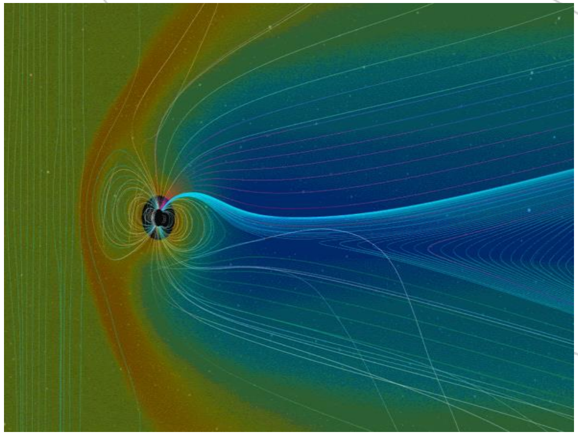




- Launched in 2014, Global Precipitation Measurement (GPM) is an international satellite mission to provide next-generation observations of rain and snow worldwide every three hours.
- Launched in 2015, Soil Moisture Active Passive (SMAP) is designed to understand the links between Earth's water, energy and carbon cycles and enhance our ability to monitor and predict natural hazards like floods and droughts

Solar Observing Missions

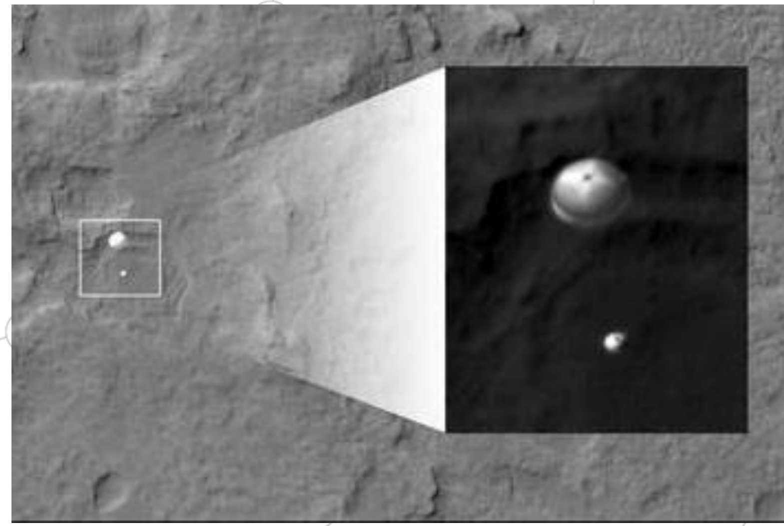


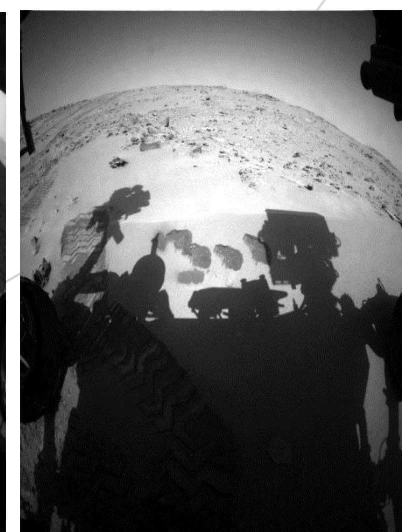


- Launched in 2015, Magnetospheric Multiscale (MMS) consists of four identical spacecraft that orbit around Earth through the dynamic magnetic system surrounding our planet to study the phenomenon called magnetic reconnection.

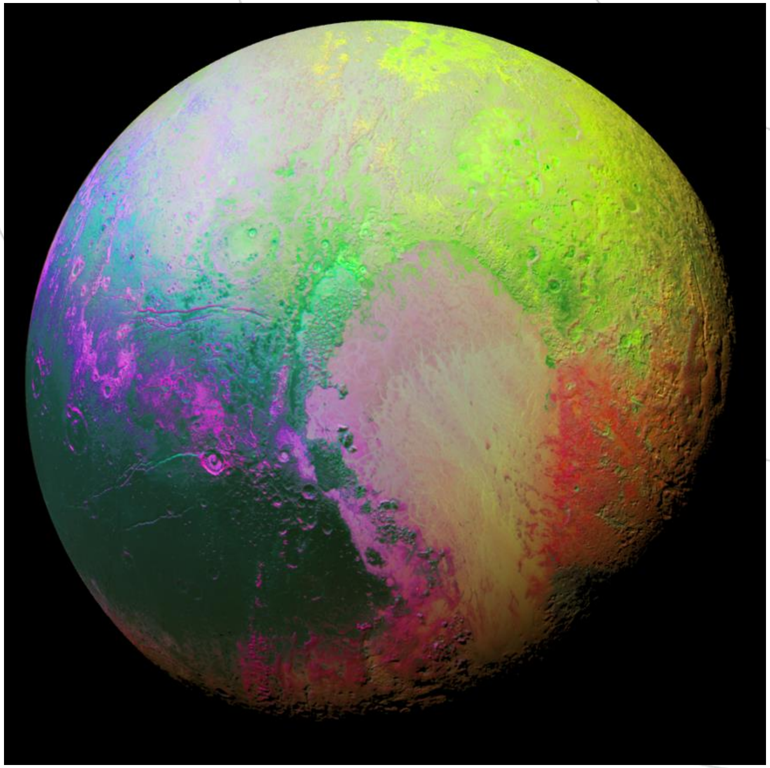
Curiosity is Exploring Mars

- The Mars Reconnaissance Orbiter (MRO) captured pictures of Curiosity's parachute.
  - MRO is supported by the Deep Space Network.
- Curiosity's first images of Mars were received by the Deep Space Network (DSN). The DSN continues to support Curiosity as it makes new discoveries.





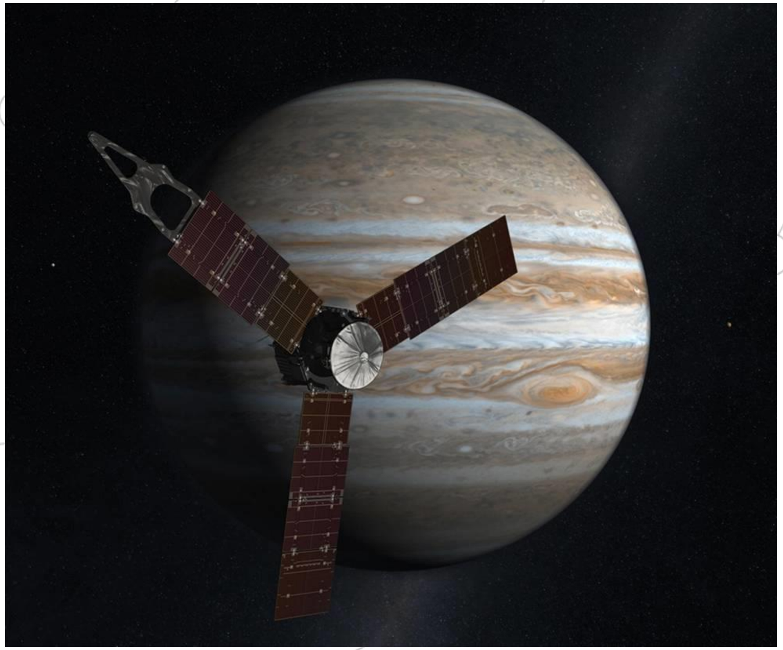
New Horizons is Beyond Pluto



- This enhanced color image of Pluto highlights the many subtle color differences between Pluto's distinct regions. The image data were collected by the spacecraft’s Ralph/MVIC color camera on July 14 from a range of 35,000 kilometers.

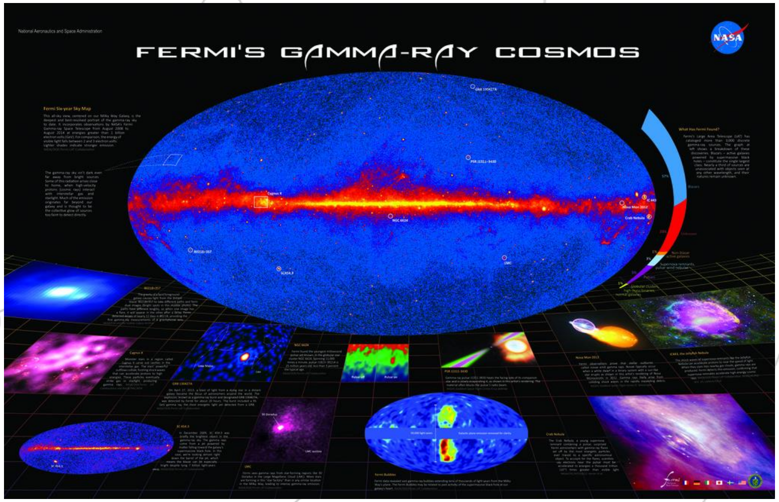
Juno is Heading Towards Jupiter

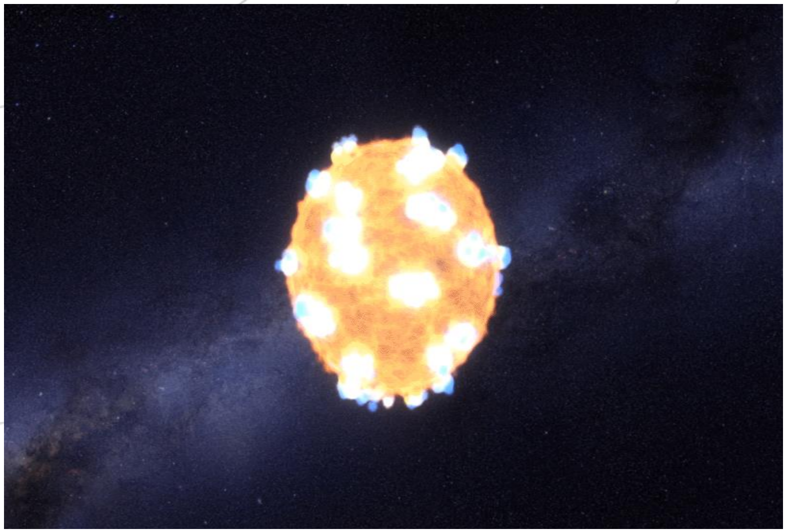
- Juno's principal goal is to understand the origin and evolution of Jupiter.
  - Underneath its dense cloud cover, Jupiter safeguards secrets to the fundamental processes and conditions that governed our solar system during its formation.
- Juno’s Jupiter insertion: July 4, 2016



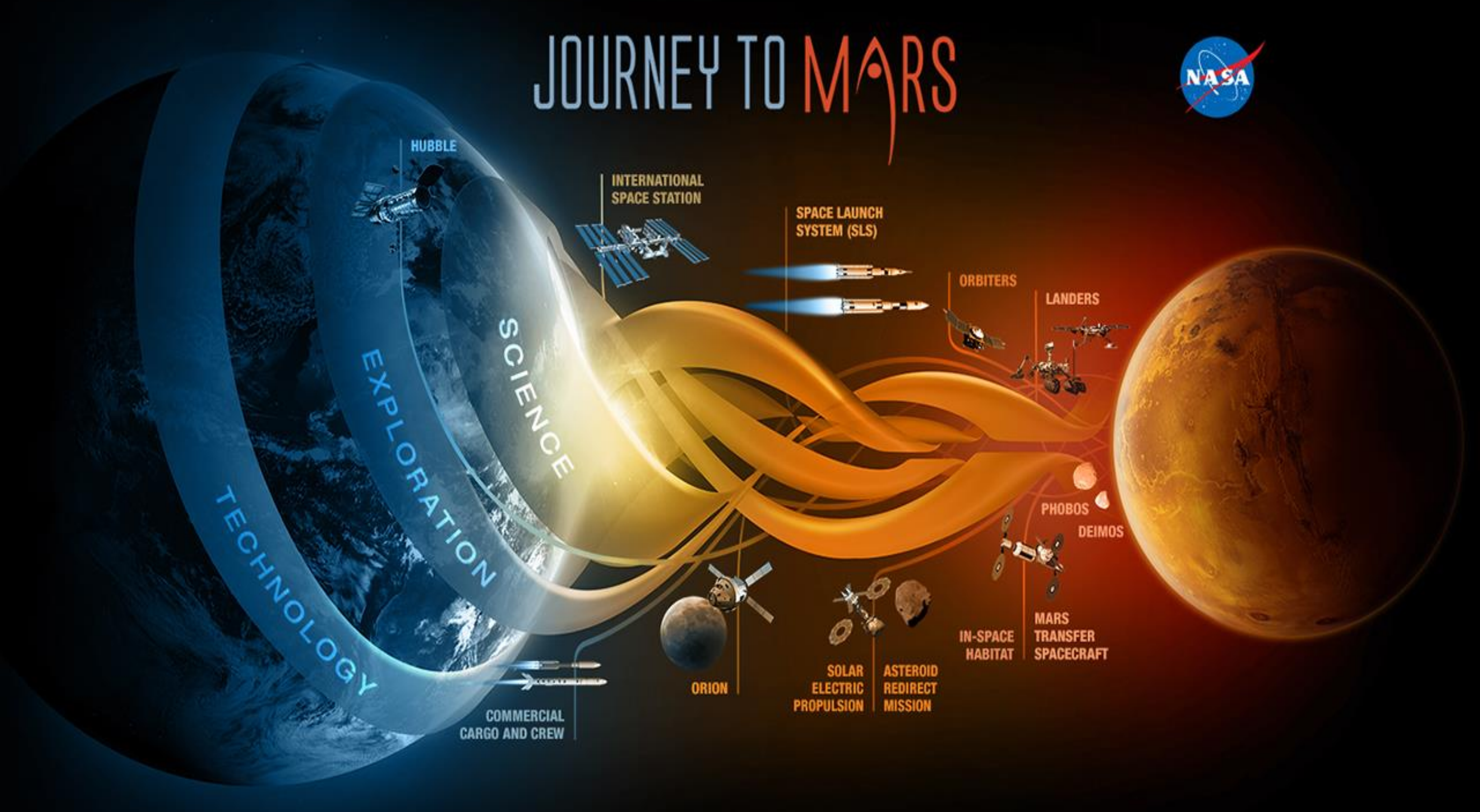
Missions Exploring the Universe

- The Fermi Gamma-ray Space Telescope that studies the cosmos in the energy range 10 keV - 300 GeV.
  - Detecting terrestrial Gamma-ray flashes at a rate of more than 800 per year.
- The Kepler Space Telescope surveys our region of the Milky Way for Earth-size and smaller planets in or near the habitable zone, determine how many stars in our galaxy might have such planets.
  - Picture is of an early flash of an exploding star

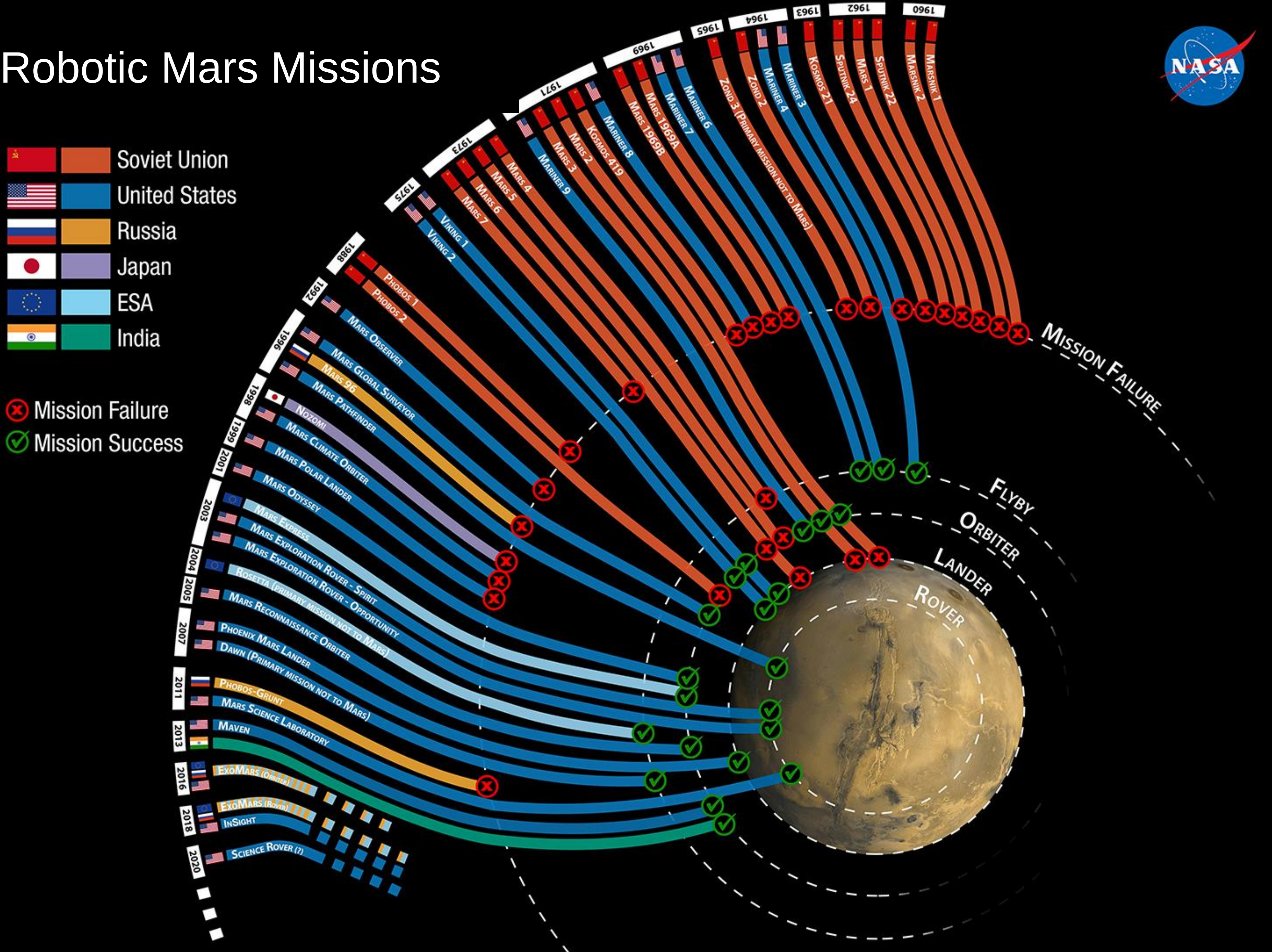




Journey to Mars…and Beyond



Robotic Mars Missions



Human Exploration of Mars is Hard

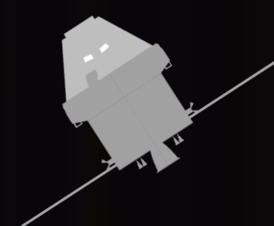
20-30 tons
Ability to land large payloads needed

130 tons
Heavy-lift mass means **multiple** launces per mission

13.5 km/s Earth re-entry speed

Reliable in-space transportation:
Total continuous transportation power

Thin atmosphere and dusty conditions for surface operations.



44 minute max two-way communication delay

20 tons of oxygen needed for ascent to orbit (ISRU)

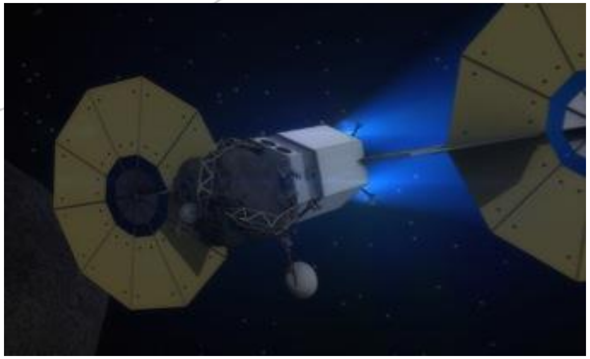
800-1100 days away from Earth in micro gravity and high levels of radiation

Humans to Mars: Achievable by Taking the Long View

- Use the ISS to retire / mitigate risks to human health and test deep space habitation technologies
- Develop multi-decadal transportation infrastructure that can support an affordable cadence and flexible launch and deployment capability
- Conduct the architecture studies and technology development needed to enable our next steps
- Engage international partners
- Facilitate commercial investment in and use of the space environment

NASA/HEOMD has more human space systems development ongoing today than at any time since Apollo!

Continuous human presence on ISS for 15 years



Human Space Exploration Phases From ISS to the Surface of Mars

Today

Phase 0: Exploration Systems ***Testing on ISS***

Ends with testing, research and demos complete*

Phase 1: ***Cislunar Flight Testing*** of Exploration Systems

Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Phase 2: ***Cislunar Validation*** of Exploration Capability

Ends with one year crewed Mars-class shakedown cruise

Phase 3: Crewed Missions Beyond Earth-Moon System

Phase 4a: Development and robotic preparatory missions

Phase 4b: Mars Human Landing Missions

Decision on destination beyond Earth-Moon system not needed until ~2020

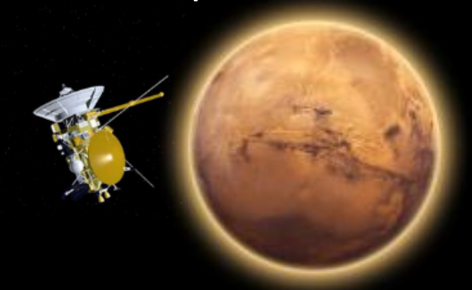
[* There are several other considerations for ISS end-of-life]

Mid-2020s

2030

What We've Learned Thus Far and Still Need to Learn

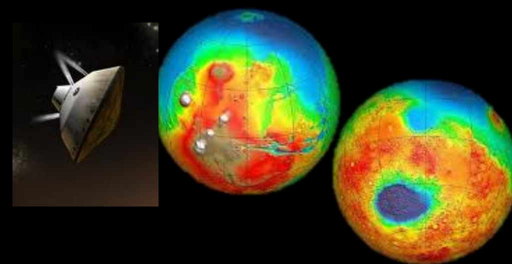
Orbital Environment and Operations



Learned:
- Deep space navigation
- Orbit transfer near low-gravity bodies
- Gravity assist
- Aero-braking
- Gravitational potential
- Mars's moons' characteristics
- ISRU potential

To Learn:
- Return flight from Mars to Earth
- Autonomous rendezvous and docking
- ISRU feasibility
- Resource characterization of Mars's moons
- High-power SEP

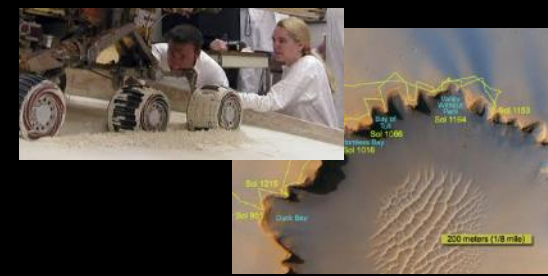
Capture, EDL, and Ascent at Mars



Learned:
- Spatial/temporal temperature variability
- Density and composition variability
- Storm structure, duration, and intensity
- 1 mT payload
- ~10 km accuracy

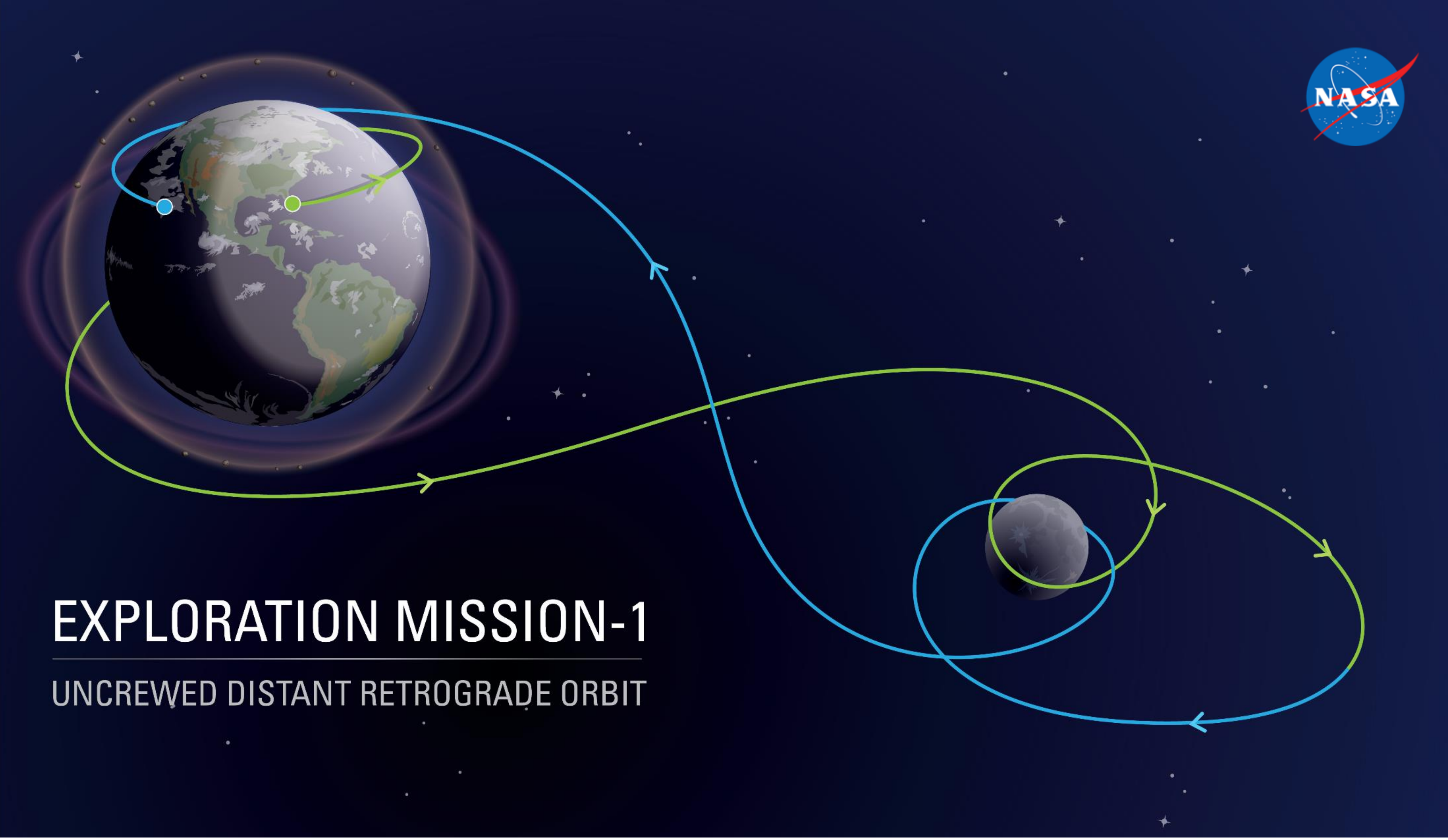
To Learn:
- Ascent from Mars
- Large-mass EDL
- Precision EDL
- Aero-capture
- Site topography and roughness
- Long-term atmospheric variability

Surface Operations at Mars



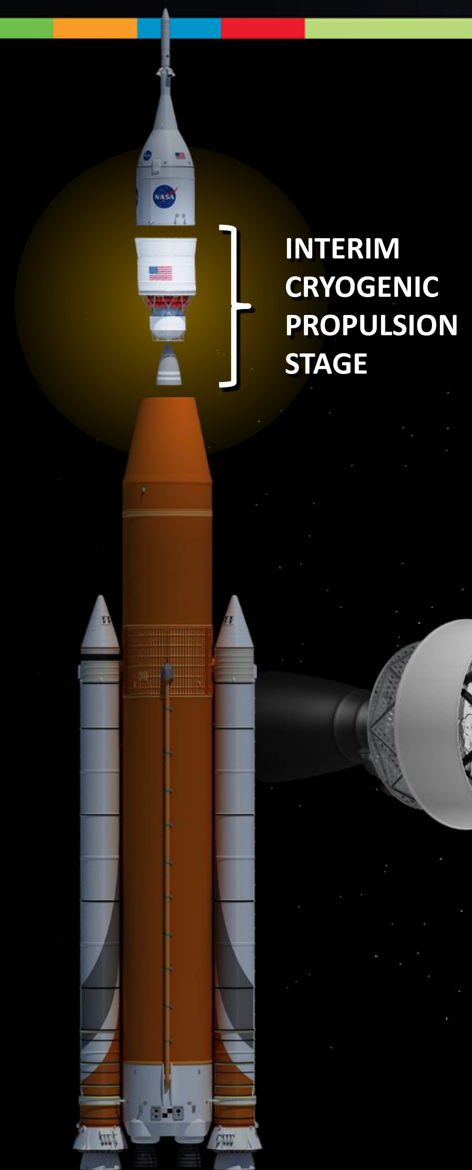
Learned:
- Water once flowed and was stable
- Global topography: elevation and boulder distributions
- Remnant magnetic field
- Dust impacts on solar power/mechanisms
- Radiation dose
- Global resource distribution
- Relay strategies, operations cadence

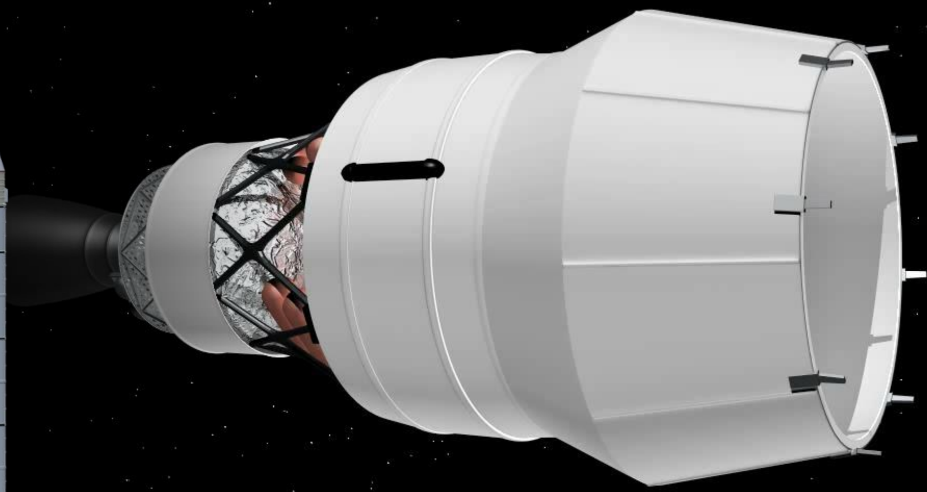
To Learn:
- Landing site resource survey
- Dust effects on human health, suits, and seals
- Rad/ECLSS in Mars environment
- Power sufficient for ISRU
- Surface navigation

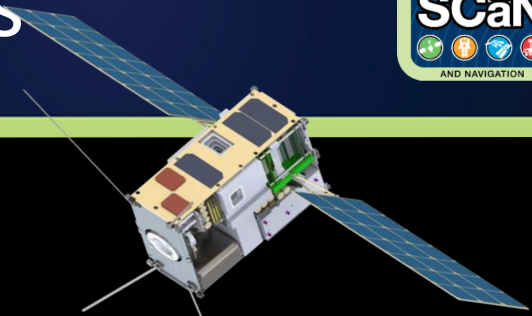


Targeted launch no later than November 2018

Secondary Payloads







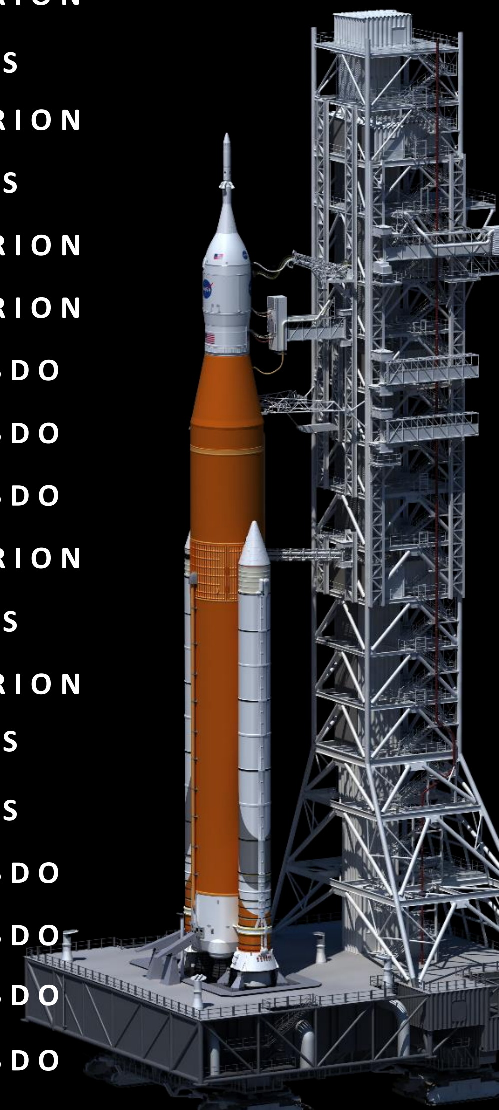
13 CUBE SATS SELECTED TO FLY ON EM-1

- Lunar Flashlight
- Near Earth Asteroid Scout
- Bio Sentinel
- LunaH-MAP
- CuSPP
- Lunar IceCube
- Skyfire
- JAXA SLSLIM
- ESA ArgoMoon
- JAXA EQUULEUS
- STMD Centennial Challenge Winners

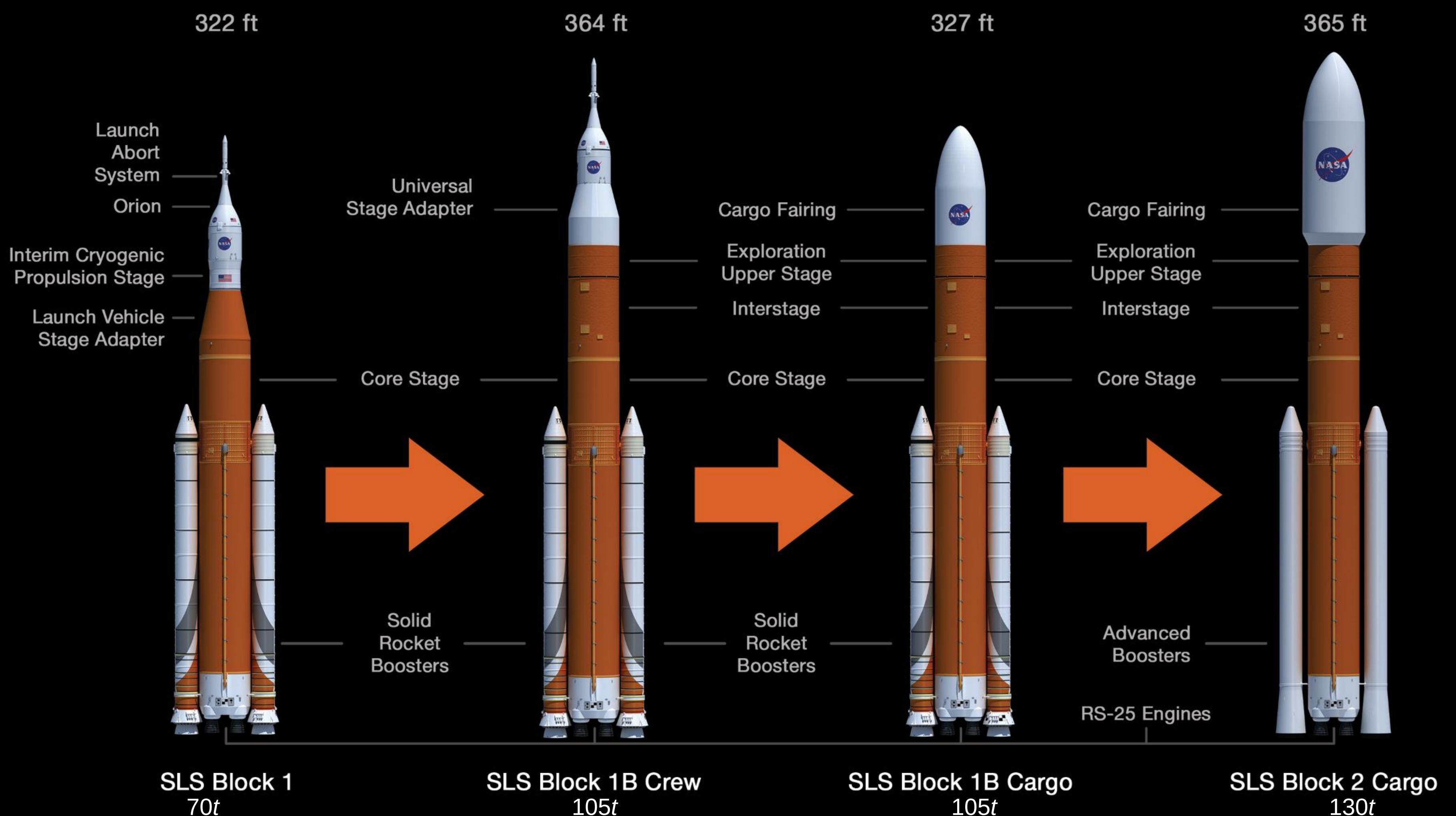
Building Exploration Mission-1

ESD PROGRAM MILESTONES

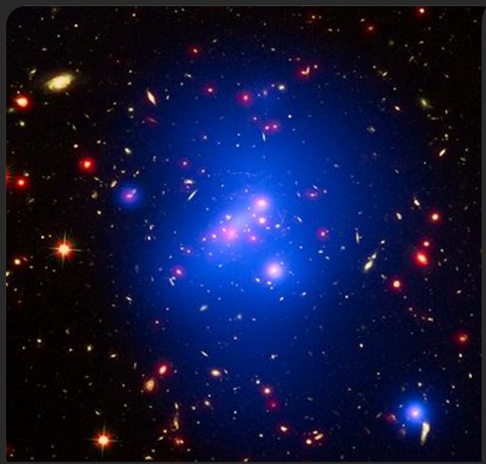
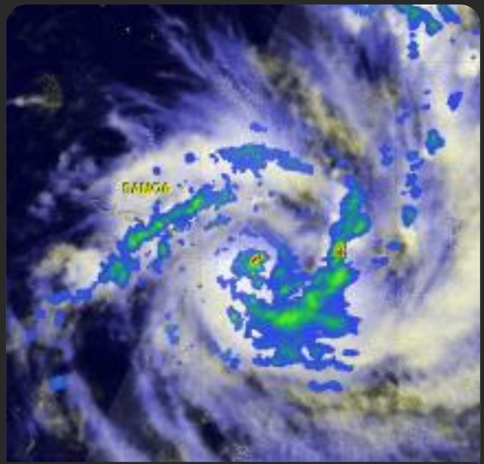
2/2016	Crew Module Pressure Vessel on Dock at Kennedy Space Center, FL	ORION
5/2016	Booster Qualification Motor 2 Test at Promontory, UT	SLS
9/2016	Crew Module Propellant Pressure Proof Test	ORION
12/2016	RS-25 Flight Engine Deliveries Complete to Michoud, New Orleans, LA	SLS
1/2017	European Service Module Delivery to Kennedy Space Center, FL	ORION
1/2017	Crew Module Initial Power On at Kennedy Space Center, FL	ORION
3/2017	Vehicle Assembly Building High Bay 3 Construction Complete	GSDO
3/2017	Launch Pad Flame trench Construction Complete	GSDO
5/2017	Mobile Launcher Ground Support Equipment Installation Complete	GSDO
7/2017	Crew Module and Service Module Mate at Kennedy Space Center, FL	ORION
8/2017	Core Stage Integration Complete at Michoud, New Orleans, LA	SLS
9/2017	Crew/Service Module Ship to Plum Brook Station for Thermal Vacuum Testing	ORION
10/2017	Core Stage Shipped to Stennis Space Center, MS	SLS
11/2017	Core Stage Green Run Hotfire Test at Stennis Space Center, MS	SLS
1/2018	Booster Stacking in Vehicle Assembly Building	GSDO
4/2018	Core Stage stacking with Boosters in Vehicle Assembly Building	GSDO
6/2018	Orion mating with SLS in Vehicle Assembly Building	GSDO
8/2018	Wet Dress Rehearsal at Launch Pad	GSDO
11/2018	EM-1 LAUNCH	



SLS Vehicle Evolution



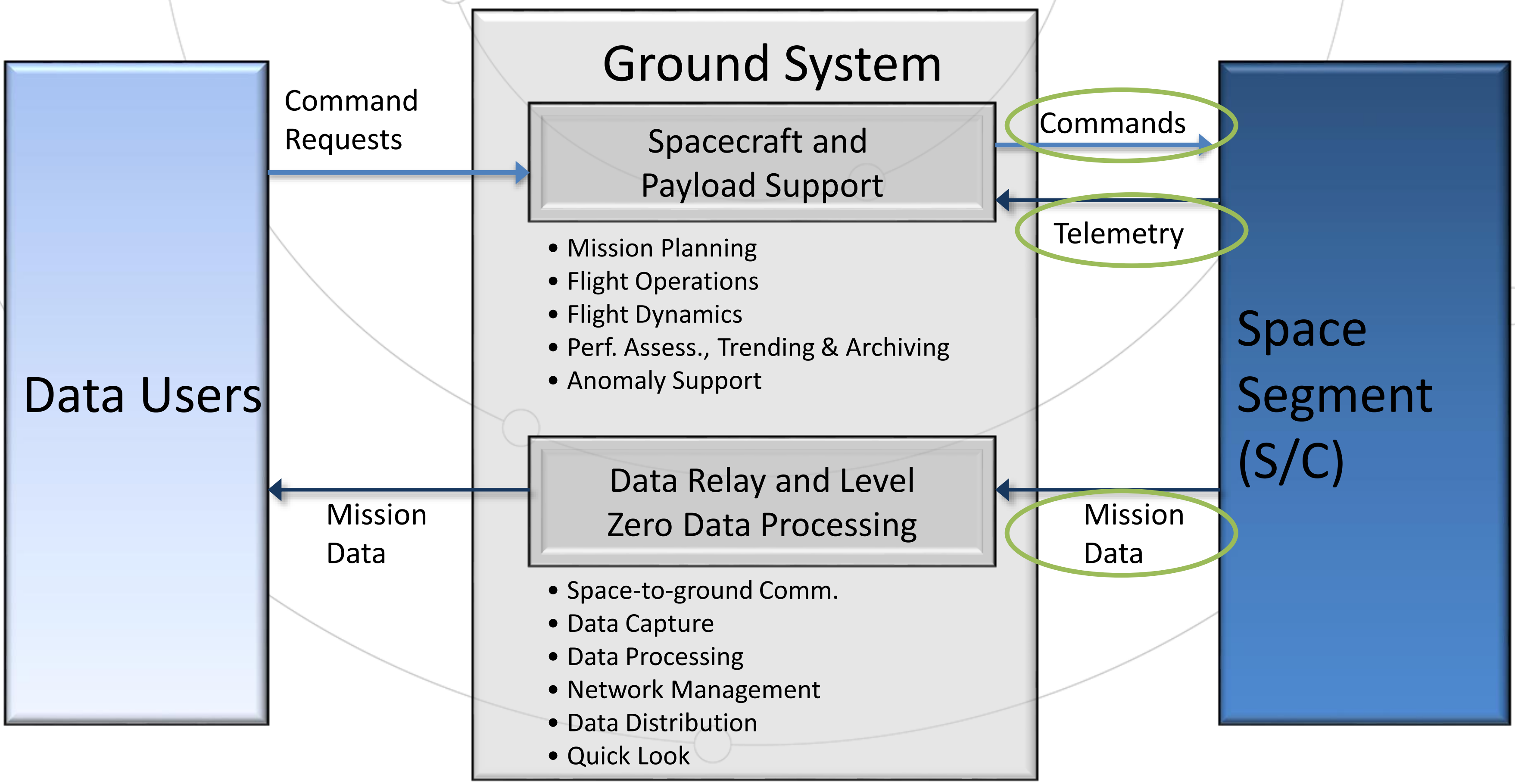
Space Communications Customers



Space Operations 101

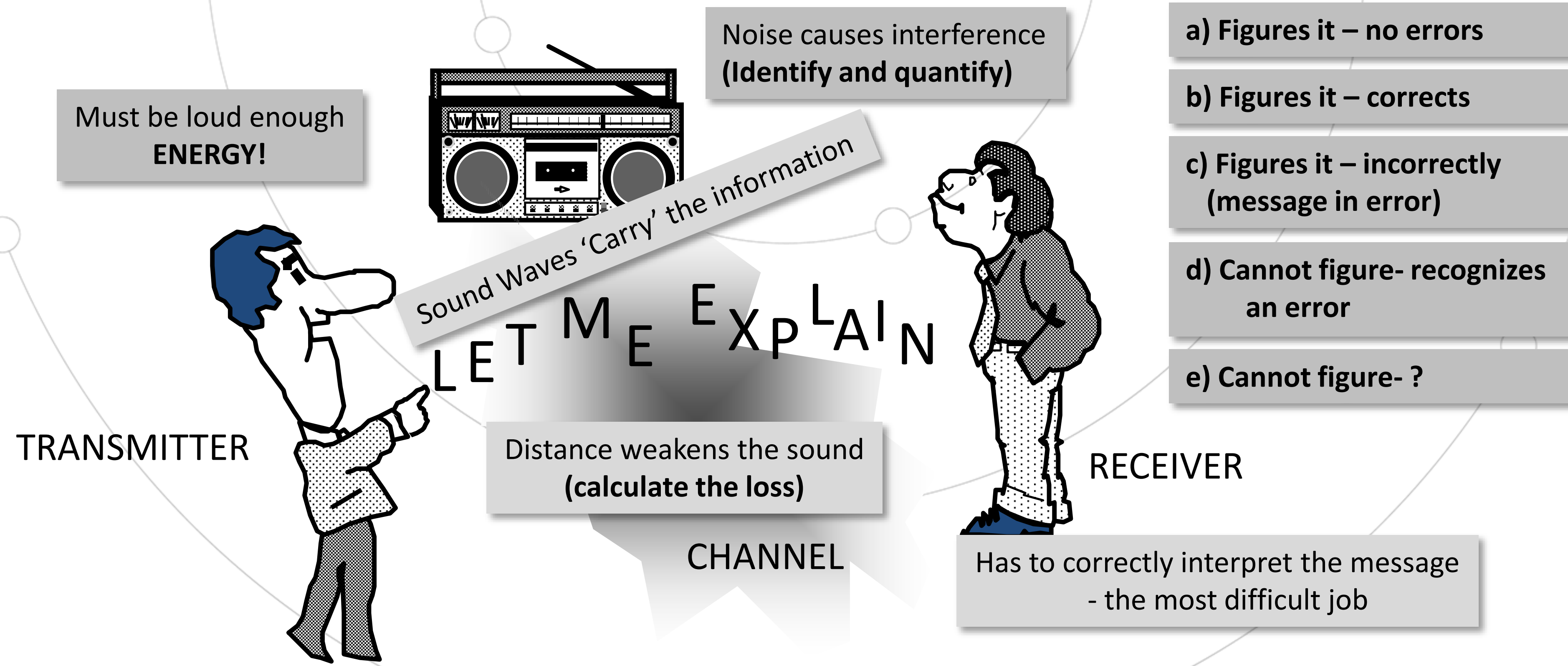
Relation Between Space Segment, Ground System, and Data Users*



* Based on Wertz and Wiley; Space Mission Analysis and Design

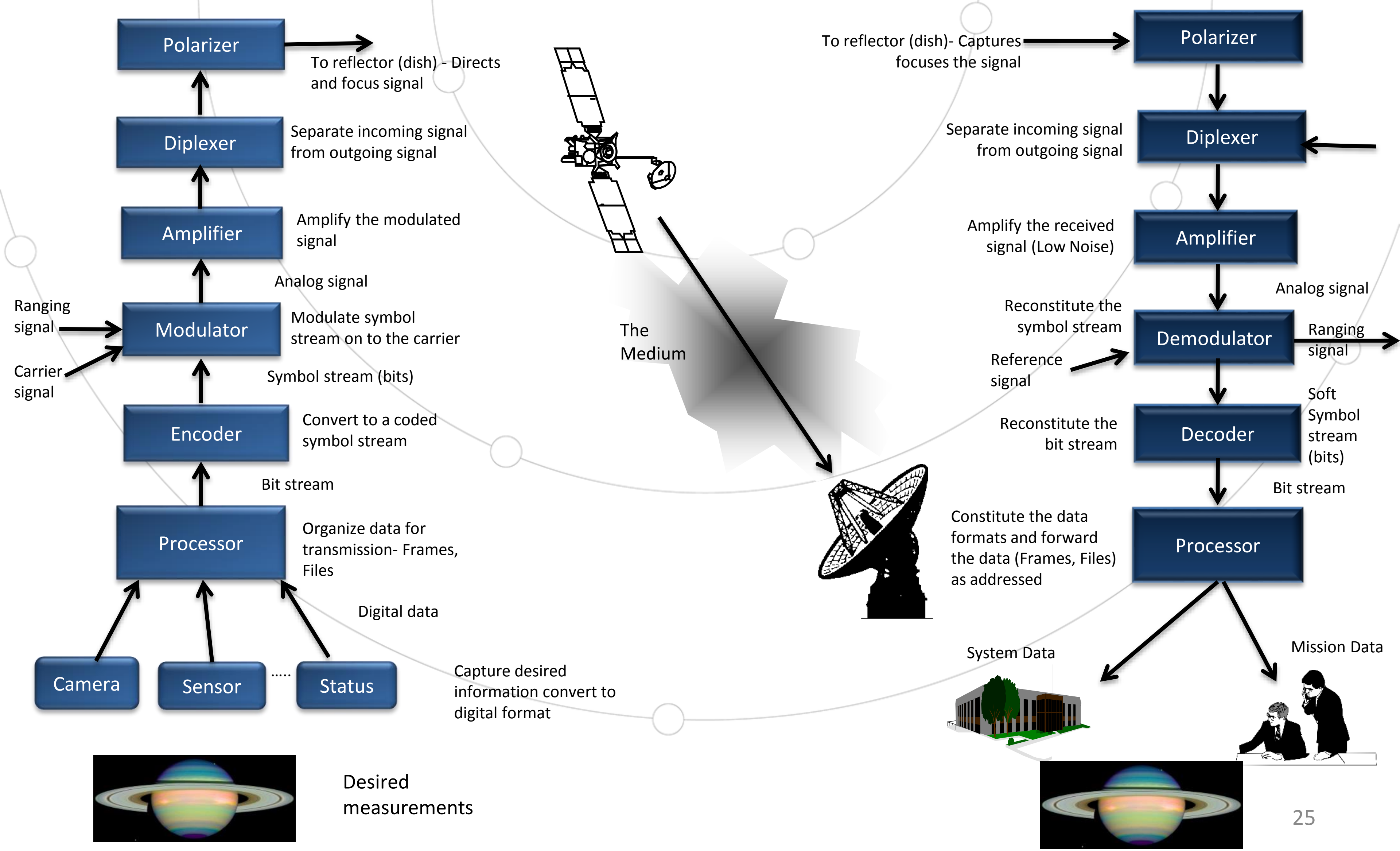
Communications Theory- Basic Concepts

Transmitter and Receiver must use the same language



The fundamental problem of communications is that of reproducing at one point either exactly or <u>approximately</u> a message selected at another point.

Functional - End to End Process



Basics: Power Transmitted and Received Antenna Gain and Propagation Loss

$$P_r = P_t \frac{1}{4\pi R^2} Ae = P_t \left(\frac{\lambda}{4\pi R}\right)^2 \left(\frac{4\pi A}{\lambda^2}\right) e$$

Power Received

Power Transmitted

Propagation Loss ($1/L_P$)

Receive Antenna Gain (G_{ant})

R = Distance or range

A = Effective area of the antenna (telescope)

Lambda = Wavelength: Higher frequency = shorter wavelength

End to End link performance

- Decreases with the square of the distance
- Increases – with inverse square of the wavelength

Antenna Gain goes up with same antenna size

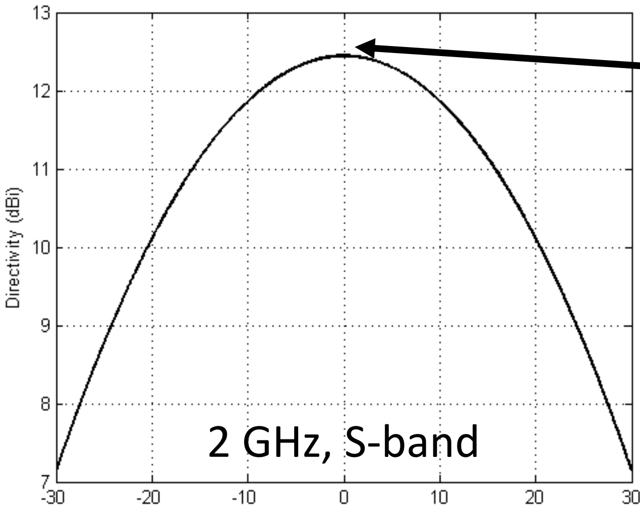
Propagation Loss

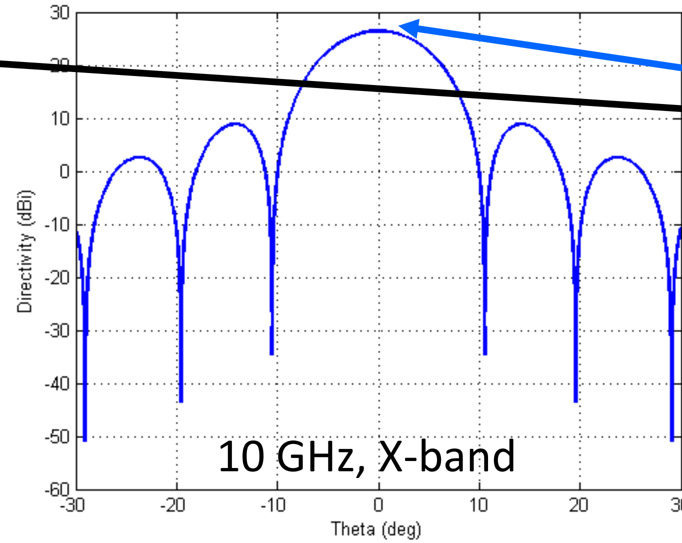
- Loss goes up as the Square of the distance!

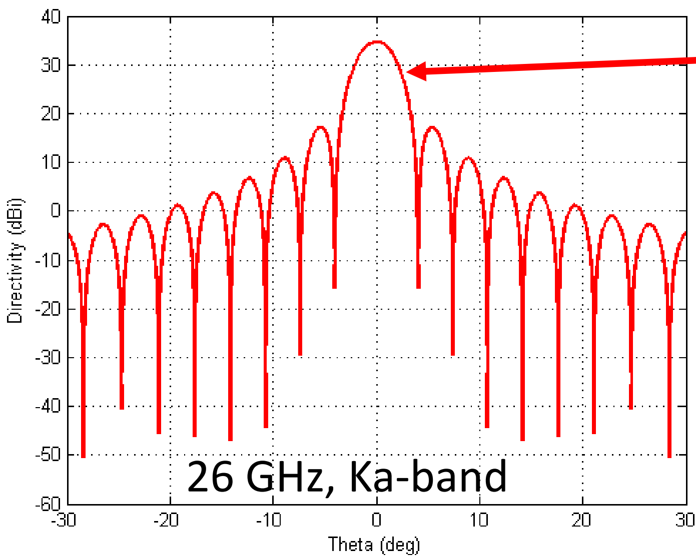
Application	Approximate Distance	Relative Difficulty
Smart Phone to cell tower	1 Km	1
TV Station to home	10 Km	100
International Space Station in Low Earth Orbit (at Closest approach)	400 Km	160,000
Comsat at GEO	40,000 Km	1,600,000,000
Mars	**300,000,000 Km**	**9×10^{16}**
Pluto	5,000,000,000 Km	2.5×10^{19}

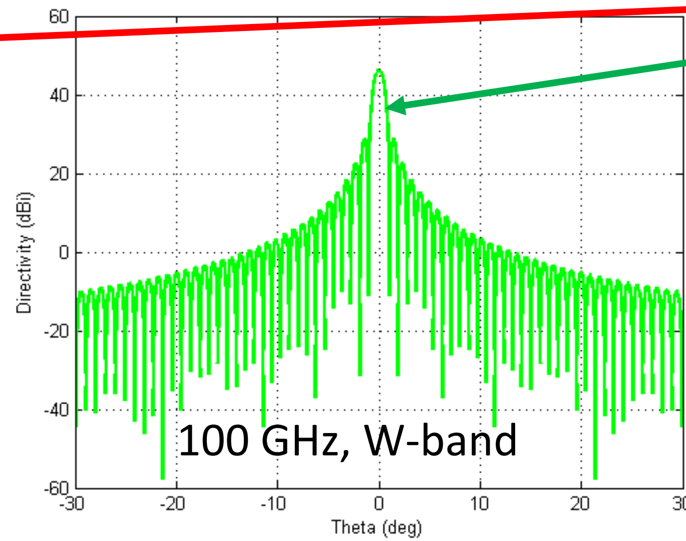
Communicating with vehicles in Space is very difficult!

How Antenna Pattern changes with Frequency .2m, parabolic antenna (uniform scale)







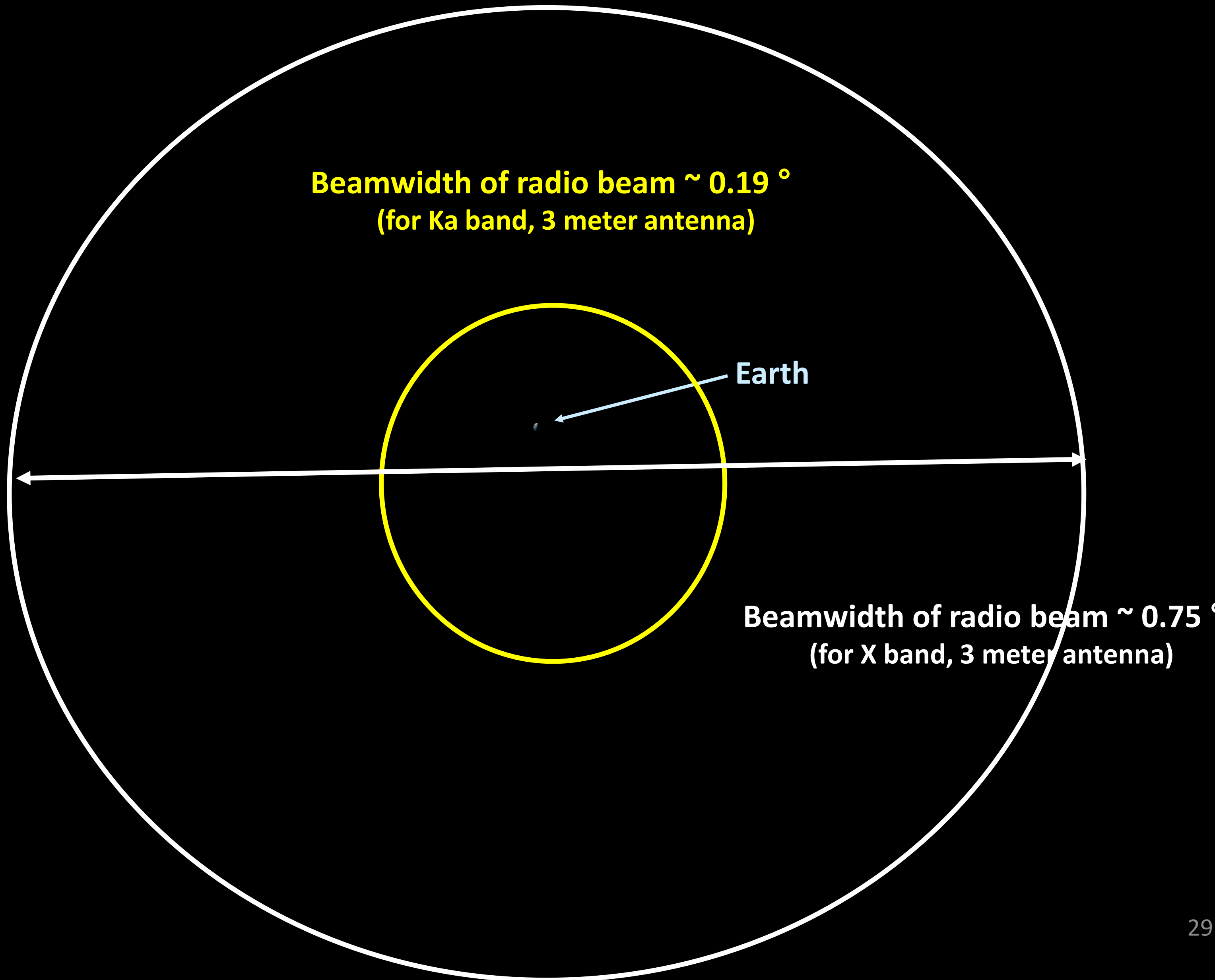


- Gain increases with frequency (able to move more data)

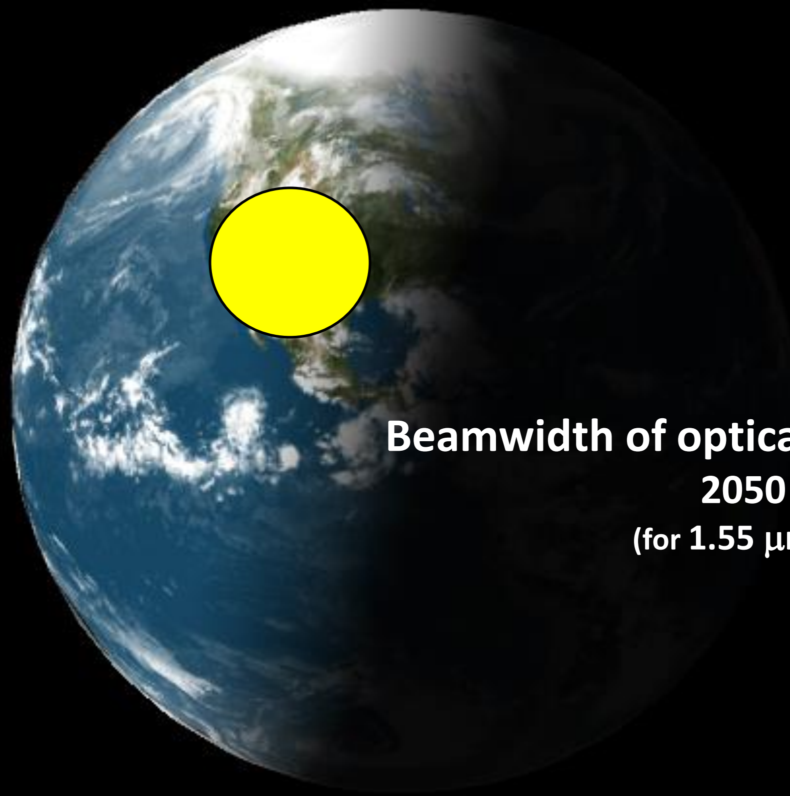
But,

- Beam width decreases with frequency (more difficult to point)

Beamwidth Example: Radio from Mars



Beamwidth Example: Optical from Mars



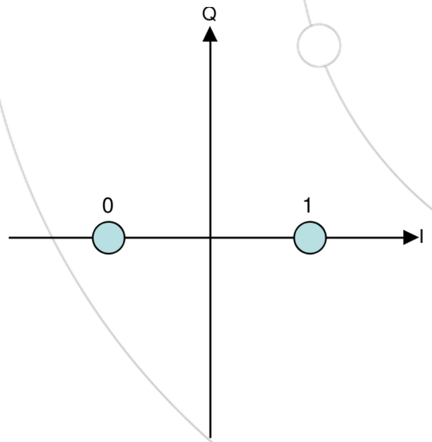
A much larger percentage of transmitted energy goes into the receiver

What is Noise?

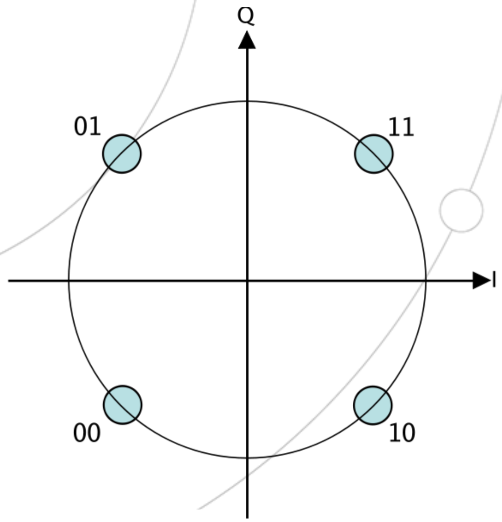
- Noise is additional “signal” that does not correspond to the information you are trying to convey.
- Noise in a signal takes several forms:
  - **Signal noise**
    - Amplitude noise – error in the magnitude of a signal
    - Phase noise – error in the frequency / phase modulation
  - **System Noise**
    - Component passive noise
    - Component active noise (amplifiers, mixers, etc…)
  - **Environmental Noise**
    - Atmospheric noise
    - Galactic noise
    - Precipitation
    - Other interfering radiating sources (e.g, Jammers)
- Noise introduces error in the “ideal” modulation and signal in free space which results in errors in the received signal at the destination

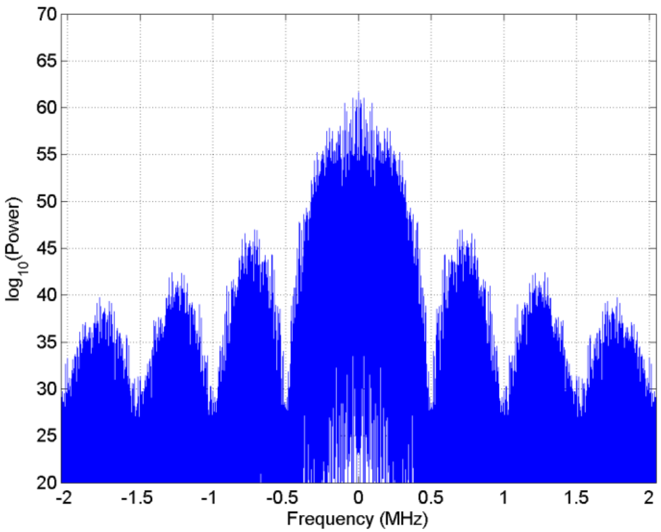
Digital Modulation

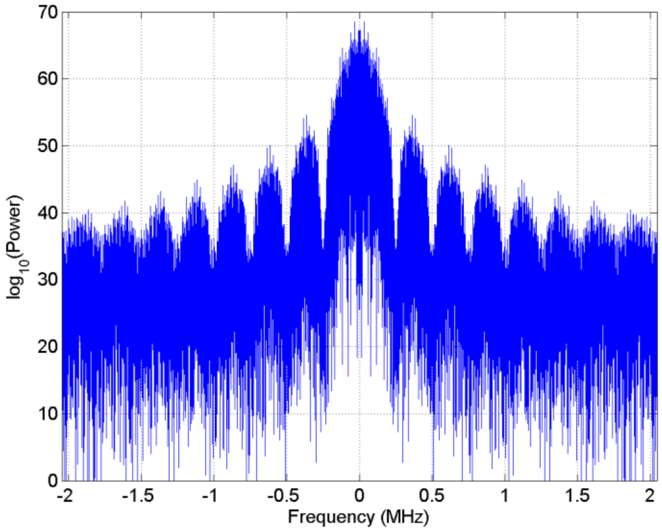
Bi-Phase Shift Keying (BPSK)



Quadrature Phase Shift Keying (QPSK)

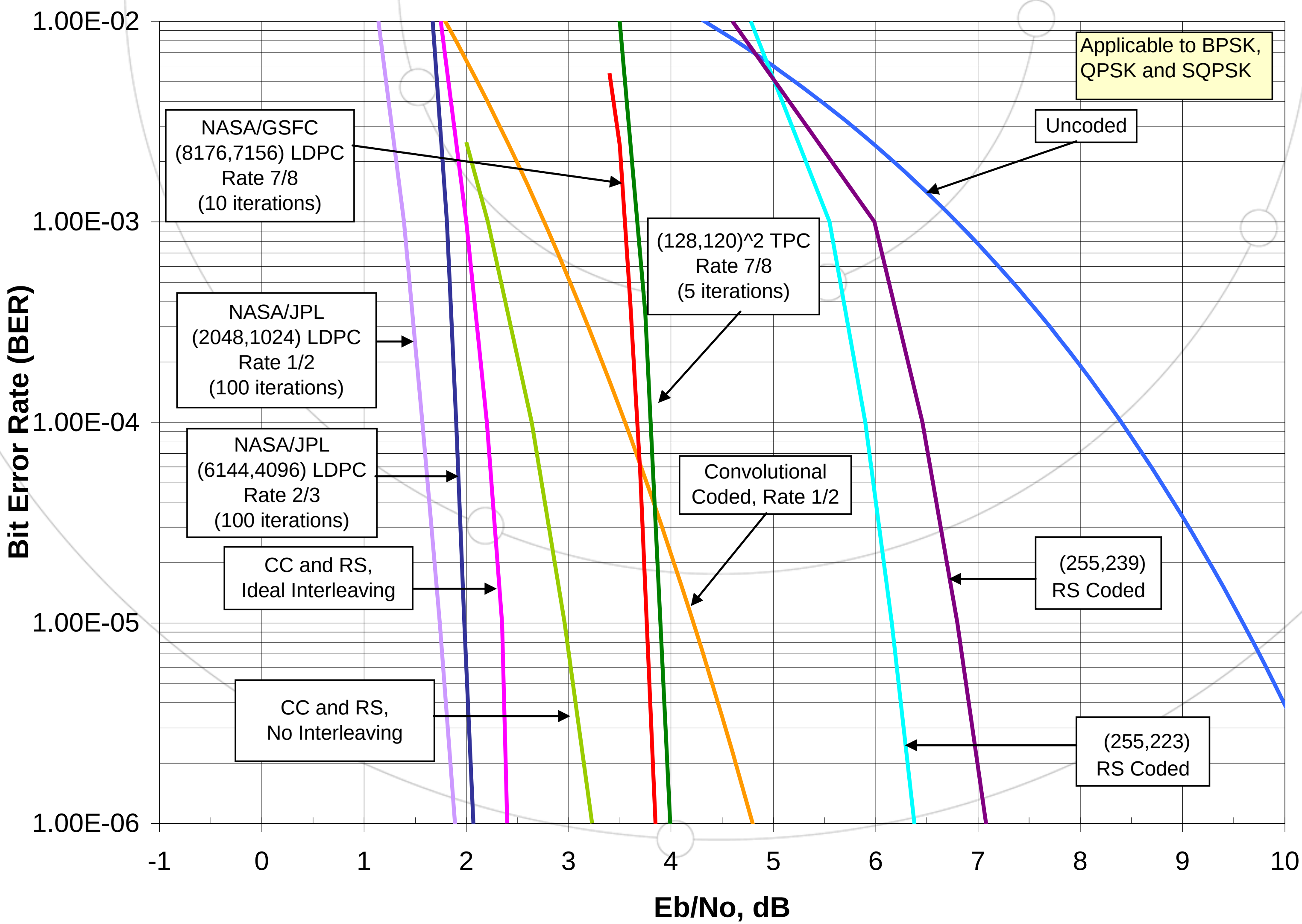






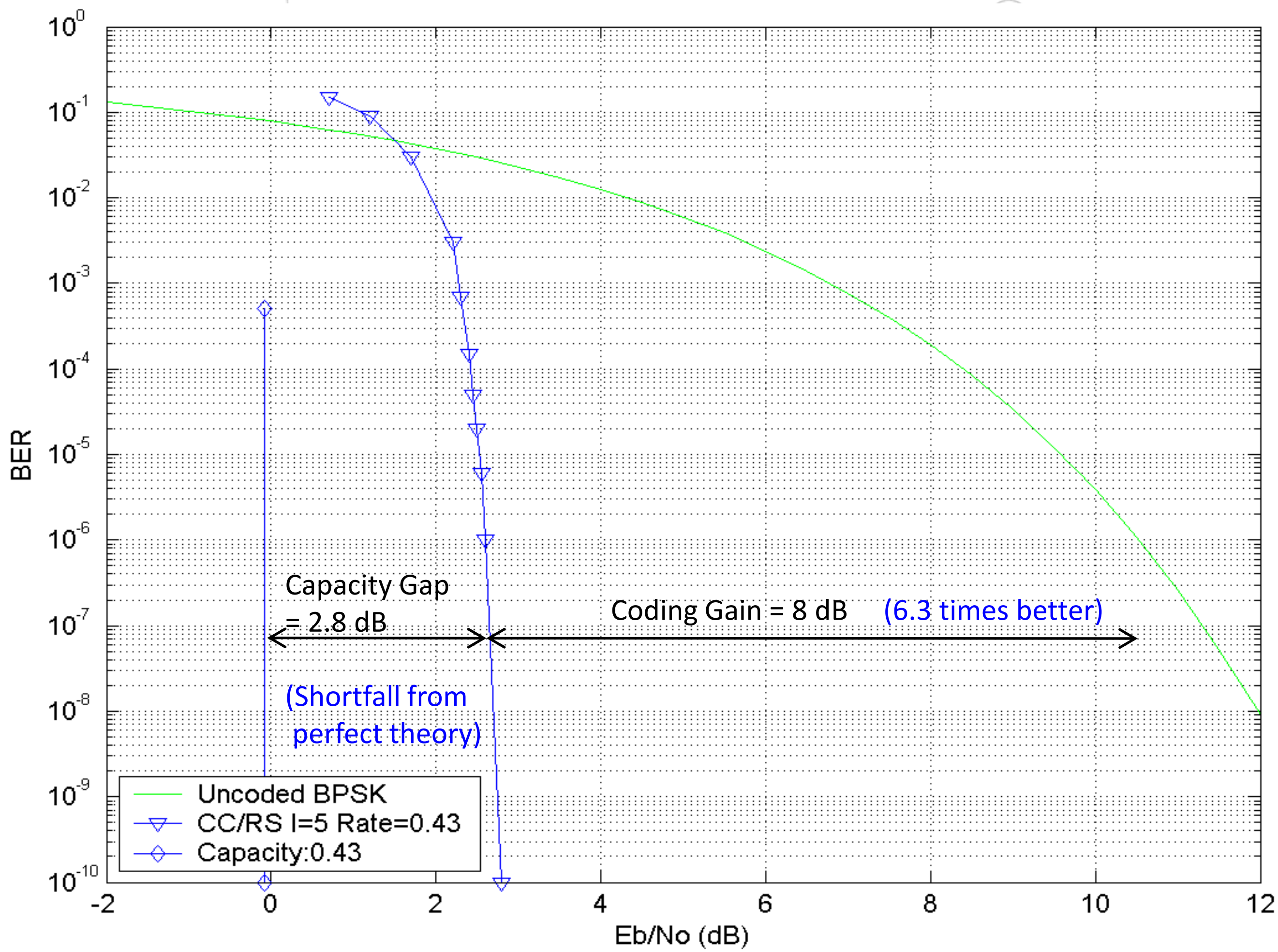
Some of Our Best Tools to Overcome Noise and Distance

Error Correcting Codes



Eb/No = Energy per bit / Noise Spectral Density

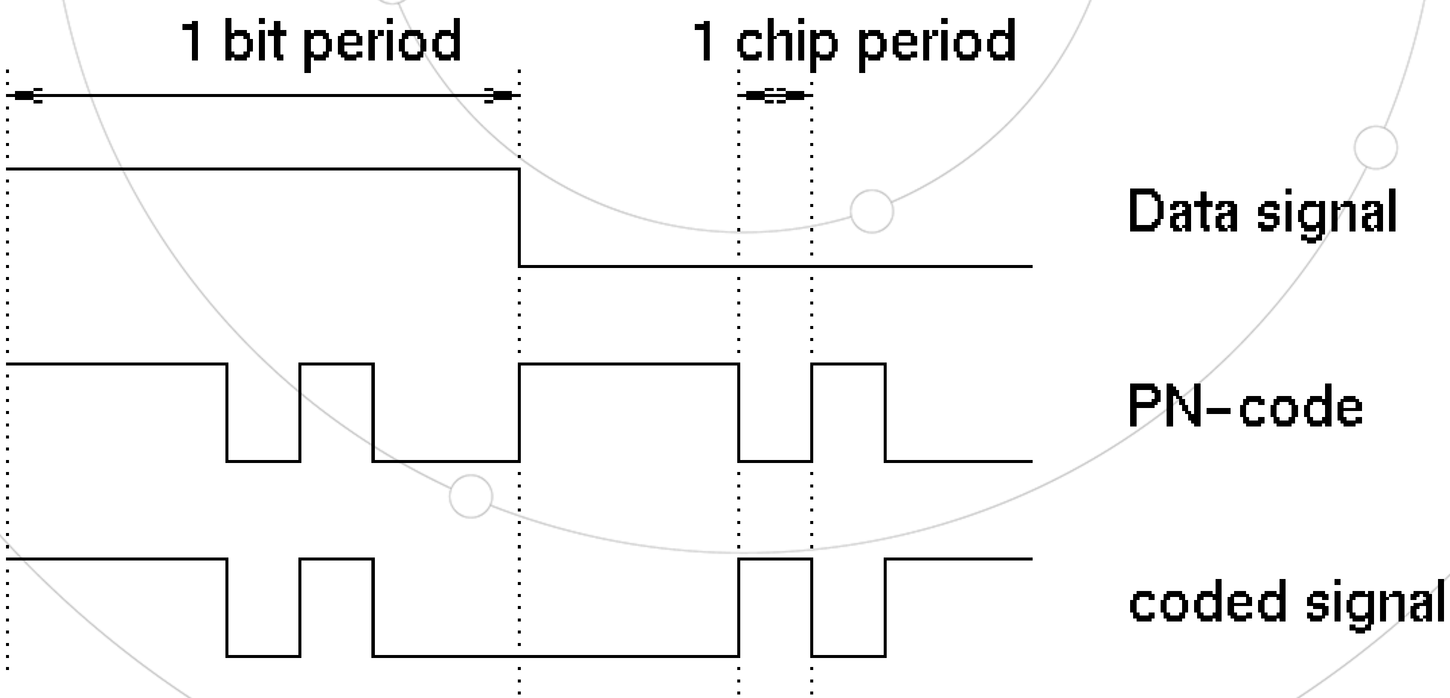
Error Correcting Coding Is High Leverage
CC/RS Coding Performance



BER = Bit Error Rate - Lower is better

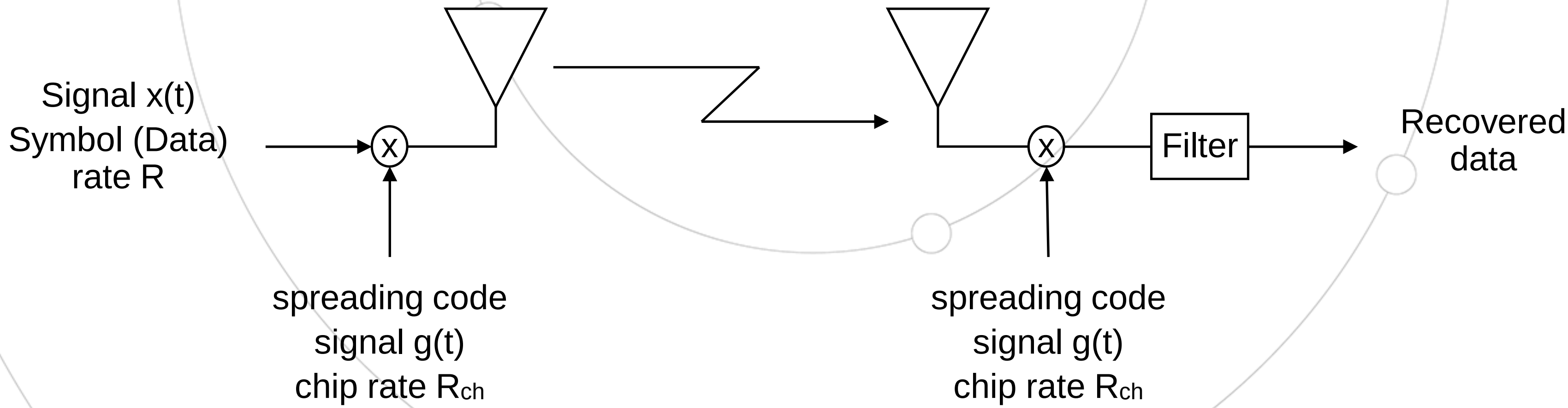
Eb/No = Energy per bit / Noise Spectrum Density

Direct Sequence Spread Spectrum to overcome interference



A DS-CDMA signal is generated by multiplication of a user data signal by a code sequence. *Source: Jack Glas, T.U. Delft*. http://www.wirelesscommunication.nl/reference/chaptr05/cdma/dscdma.htm)

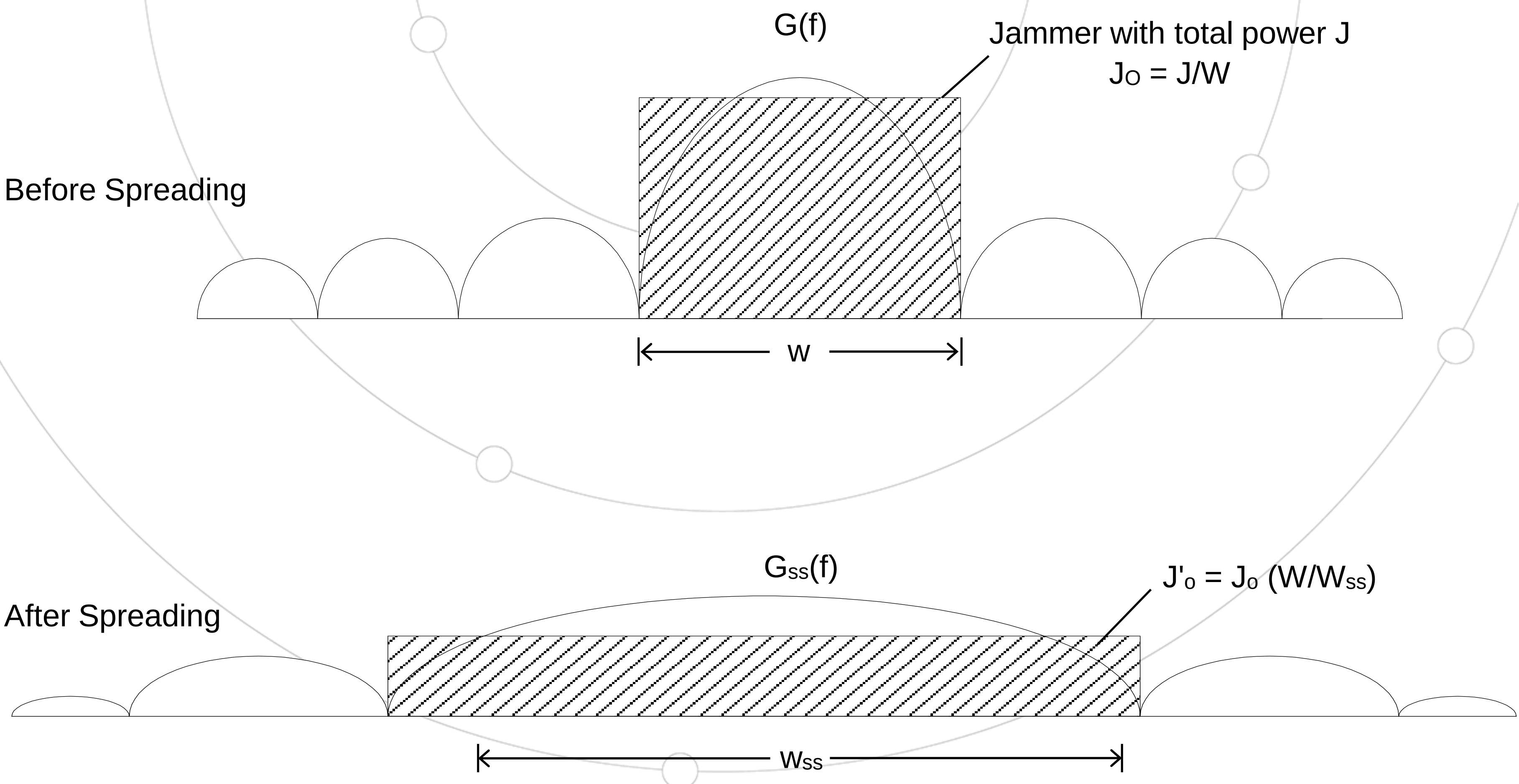
Receiving Direct Sequence Spread Spectrum Signals



$R_{ch} \approx \geq 10$ symbol (data) rate

- Multiplication by the spreading signal once spreads the signal bandwidth.
- Multiplication by the spreading signal twice recovers the original signal.
- The desired signal gets multiplied twice, but the jamming signal gets multiplied only once.
- g(t) must be deterministic, since it must be generated at both the transmitter and receiver, yet it must appear random to authorized listeners.
  - Generally g(t) is generated as a pre-defined pseudo-random sequence of 1s and 0s through the use of prescribed shift registers.

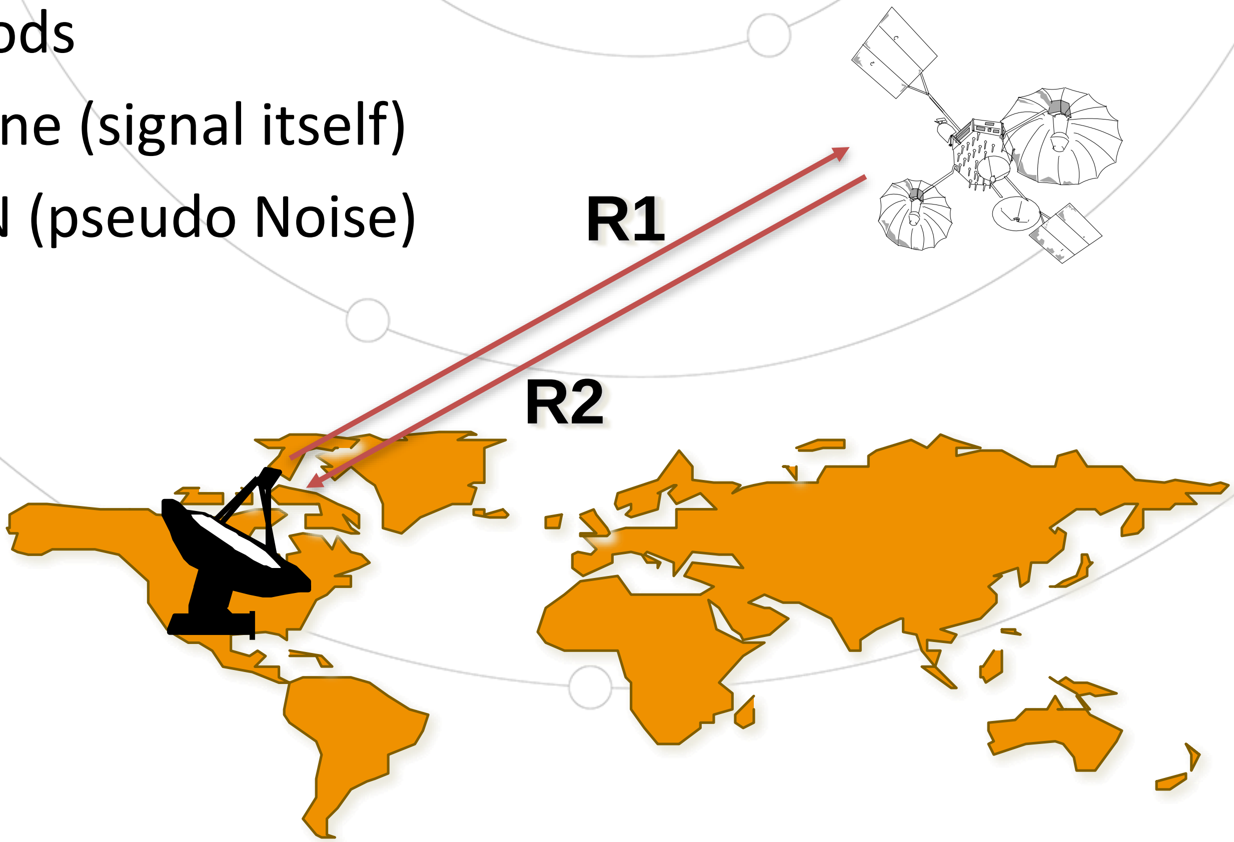
Spreading: Effect of Spread Spectrum



- To achieve successful space communication with microwaves you need:
  - **Line of sight** between the space vehicle and the receiver
  - **Ability to point** the antennas at each other (PAT)
  - **Sufficient received signal power** compared to background noise
    - Large antennas
    - Ultra low noise cooled preamplifiers
    - Large transmitters (ground stations)
  - Use of **error correcting coding** and **disruption tolerant protocols** to improve performance in **noise**
  - With increased distances these become even more important
  - Typically integrated **metric tracking** measurements

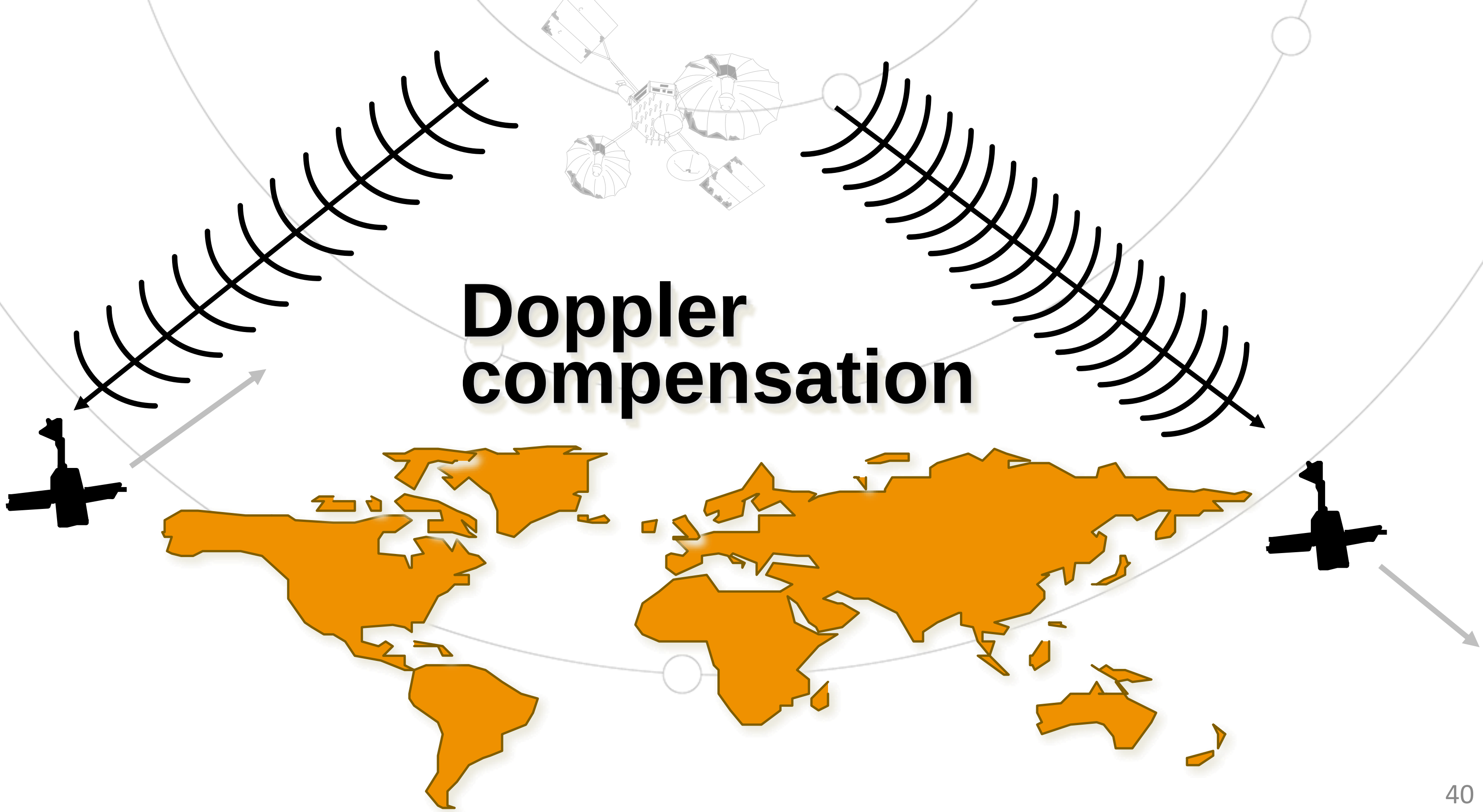
Metric Tracking Ranging

- Range is the distance from ground station to spacecraft.
  - Usually measured as "Round-trip" ranging: station, to spacecraft (R1), to station (R2). AKA, RTLT, Round-trip light time.
  - Distance = (RTLT/2) * light speed
- Methods
  - Tone (signal itself)
  - PN (pseudo Noise)



Metric Tracking Doppler = Range Rate

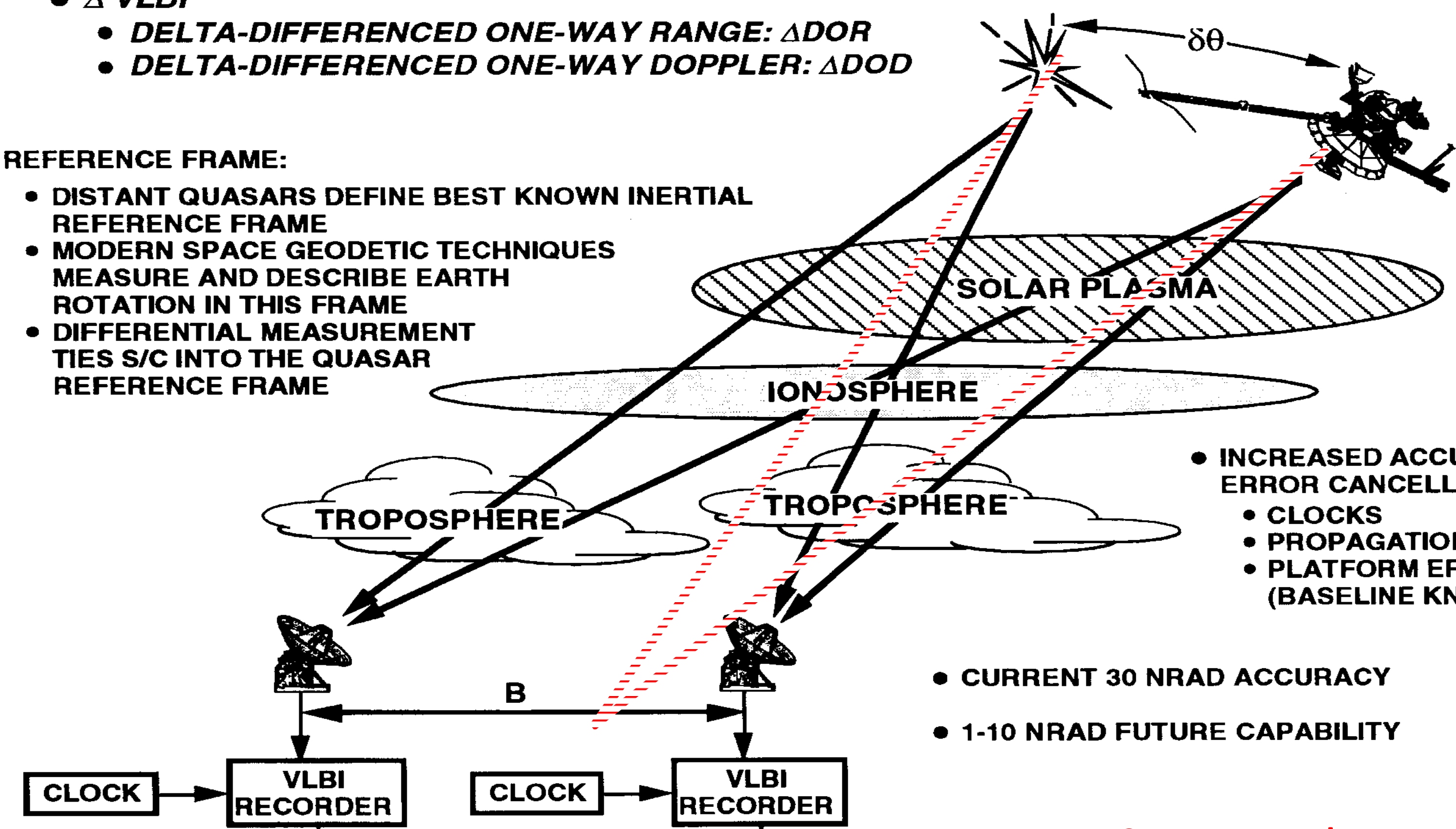
An observed/perceived change in the frequency of a radio wave due to the rate of change in distance (relative velocity) between transmitter and receiver.



Spacecraft-Quasar Differential Angular Techniques

- *Δ VLBI*
  - *DELTA-DIFFERENCED ONE-WAY RANGE: ΔDOR*
  - *DELTA-DIFFERENCED ONE-WAY DOPPLER: ΔDOD*

- REFERENCE FRAME:
  - DISTANT QUASARS DEFINE BEST KNOWN INERTIAL REFERENCE FRAME
  - MODERN SPACE GEODETIC TECHNIQUES MEASURE AND DESCRIBE EARTH ROTATION IN THIS FRAME
  - DIFFERENTIAL MEASUREMENT TIES S/C INTO THE QUASAR REFERENCE FRAME



$$\Delta\rho_{s/c} = B \cos\theta_{s/c} + c\,(\Delta\tau_{clock} + \Delta\tau_{inst} + \Delta\tau_{media}) + \text{NOISE}$$
$$\Delta\rho_{Q} = B \cos\theta_{Q} + c\,(\Delta\tau_{clock} + \Delta\tau_{inst} + \Delta\tau_{media}) + \text{NOISE}$$

- INCREASED ACCURACY DUE TO ERROR CANCELLATION:
  - CLOCKS
  - PROPAGATION MEDIA
  - PLATFORM ERRORS (BASELINE KNOWLEDGE)

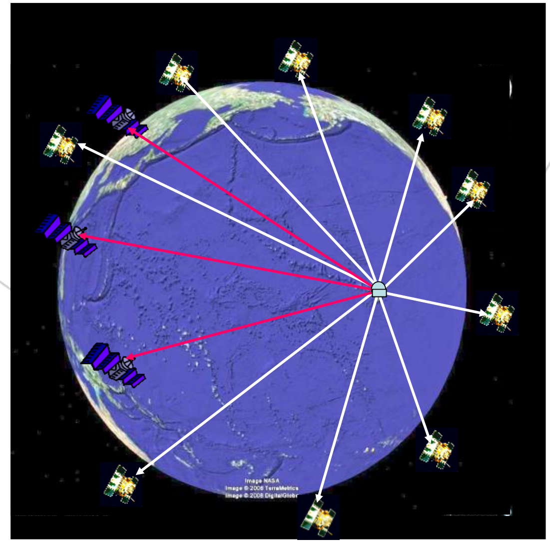
- CURRENT 30 NRAD ACCURACY
- 1-10 NRAD FUTURE CAPABILITY

- Common-modes out most error sources
- Leaves accurate measure of S/C-to-Quasar separation angle

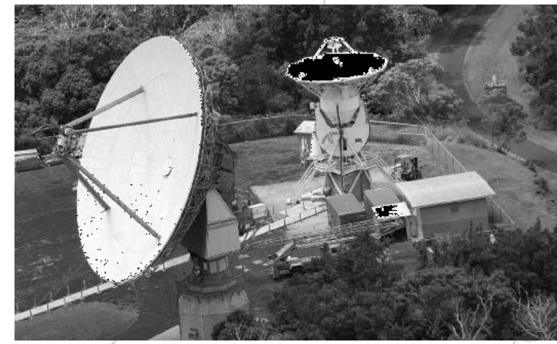
GPS Space Applications Critical to a Range of Space Operations, Science, and Exploration Enterprises

GPS services already enable:

- **Real-time On-Board Autonomous Navigation:**
  - Reduces the burden and costs
  - Enables new methods of spaceflight such as precision formation flying and station-keeping
- **Attitude Determination:**
  - Used on the ISS
- **Earth Sciences:**
  - Remote sensing tool supports atmospheric and ionospheric sciences
  - Geodesy, and geodynamics -- from monitoring sea level heights and climate change to understanding the gravity field
- **International space agencies planning to use similar robust capabilities from Galileo and other GNSS constellations**



GPS / QZSS monitoring station at Kokee Park, Hawaii (NASA –JAXA 2009 Agreement)



Jules Verne ATV during rendezvous with ISS in 2008

- GPS relative navigation used
- Future navigation on ATV to be performed via combined GPS/Galileo receiver

Current SCaN Networks

Near Earth Network (NEN)

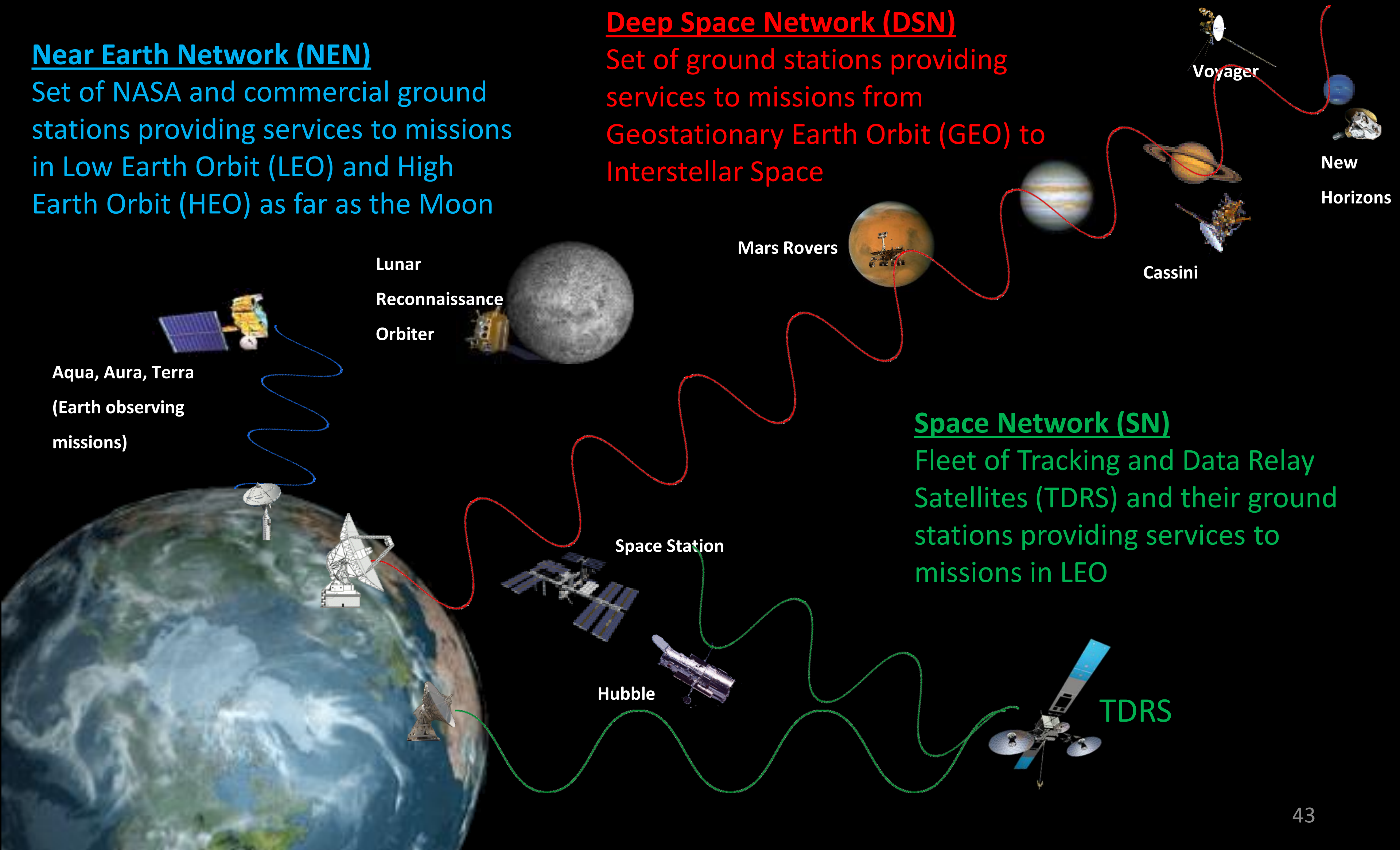
Set of NASA and commercial ground stations providing services to missions in Low Earth Orbit (LEO) and High Earth Orbit (HEO) as far as the Moon

Deep Space Network (DSN)

Set of ground stations providing services to missions from Geostationary Earth Orbit (GEO) to Interstellar Space

Space Network (SN)

Fleet of Tracking and Data Relay Satellites (TDRS) and their ground stations providing services to missions in LEO



NASA Networks Span the Globe

Deep Space Network
Near Earth Network
Space Network

Orbits and View

Deep Space Network

Provides continual tracking to spacecraft above 30,000 km altitude

- 3 complexes around the Earth
- 34 to 70 meter antennas on the Earth

Space Network

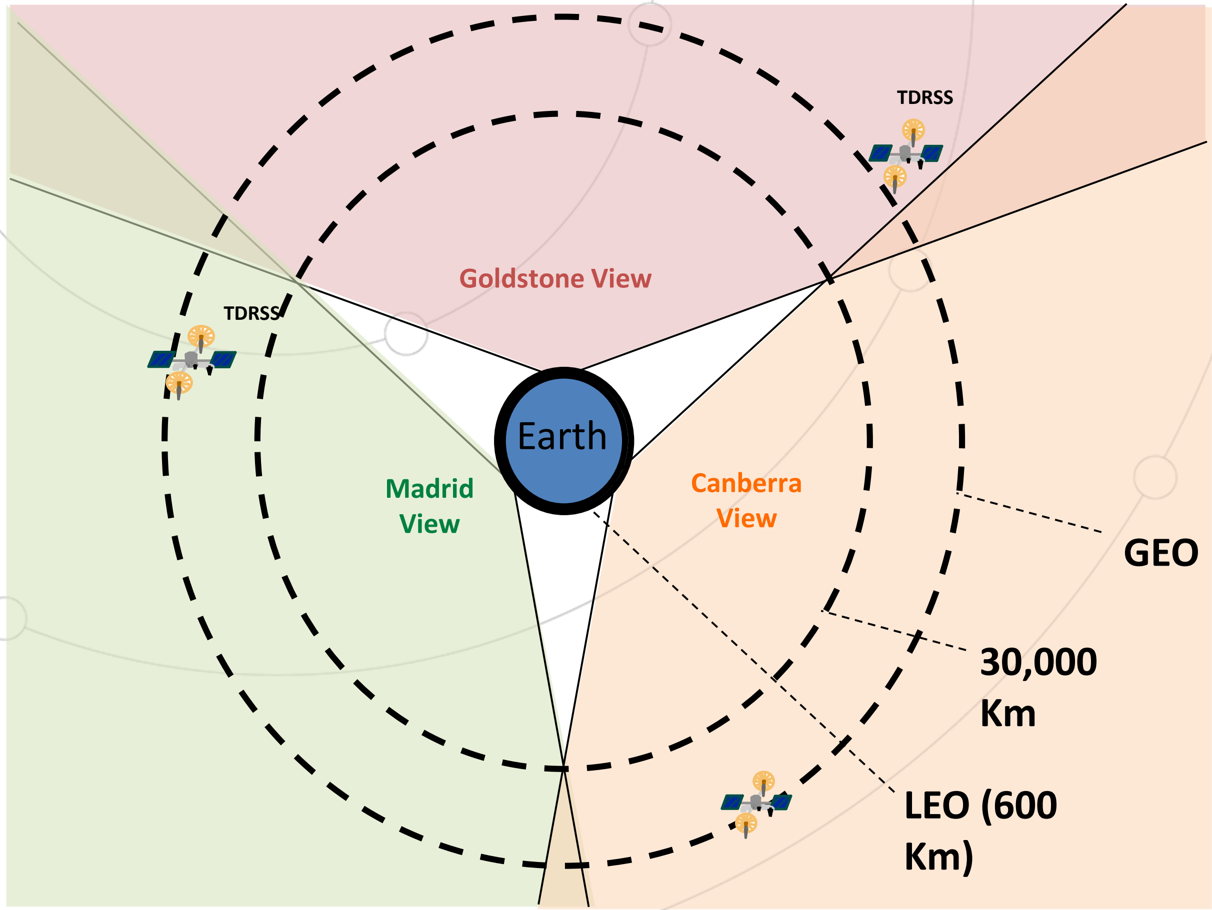
Provides continuous tracking of spacecraft below GEO

- Constellation of relay spacecraft at three nodes around the Earth
- 5 meter tracking antennas in space

Near Earth Network

Provides tracking of near earth orbiting spacecraft.

- 10 to 18 meter antennas on the Earth



View looking down on the Earth's North Pole

Together they provide nearly continuous coverage across the Solar System!

Overview of the Three Networks

Deep Space Network

Three global ground stations providing services to missions from Geostationary Earth Orbit (GEO) to beyond our solar system.

Focused on detecting and differentiating faint signals from stellar noise

Missions include: Kepler, Cassini Mars Rovers and Orbiters , Mars Science Laboratory (Curiosity) Voyagers 1 and 2, Spitzer Space Telescope

Near Earth Network

Set of world-wide NASA and commercial ground stations providing services to missions in Low Earth Orbit (LEO) and High Earth Orbit (HEO) as far as the Moon.

Missions include: Aqua, Aura, Lunar Reconnaissance Orbiter, Landsat, Radiation Belt Storm Probes

Space Network

Fleet of Tracking and Data Relay Satellites (TDRS) and their ground stations providing services to missions in Low Earth Orbit (LEO)

Optimized for continuous, high data rate communications

Critical for human spaceflight safety and critical event coverage

Missions include: International Space Station, ISS Resupply, Hubble Space Telescope, Terra, Fermi Gamma- Ray Space Telescope

Near Earth Network

NASA Stations

- Alaska Satellite Facility, Alaska (two 11 meter, one 10 meter antennas)
- McMurdo Grounds Station, Antarctica (one10 meter antenna)
- Wallops Ground Station, Virginia (one 5 meter, one 11 meter antennas)
- White Sands Complex, New Mexico (one 18 meter antenna)

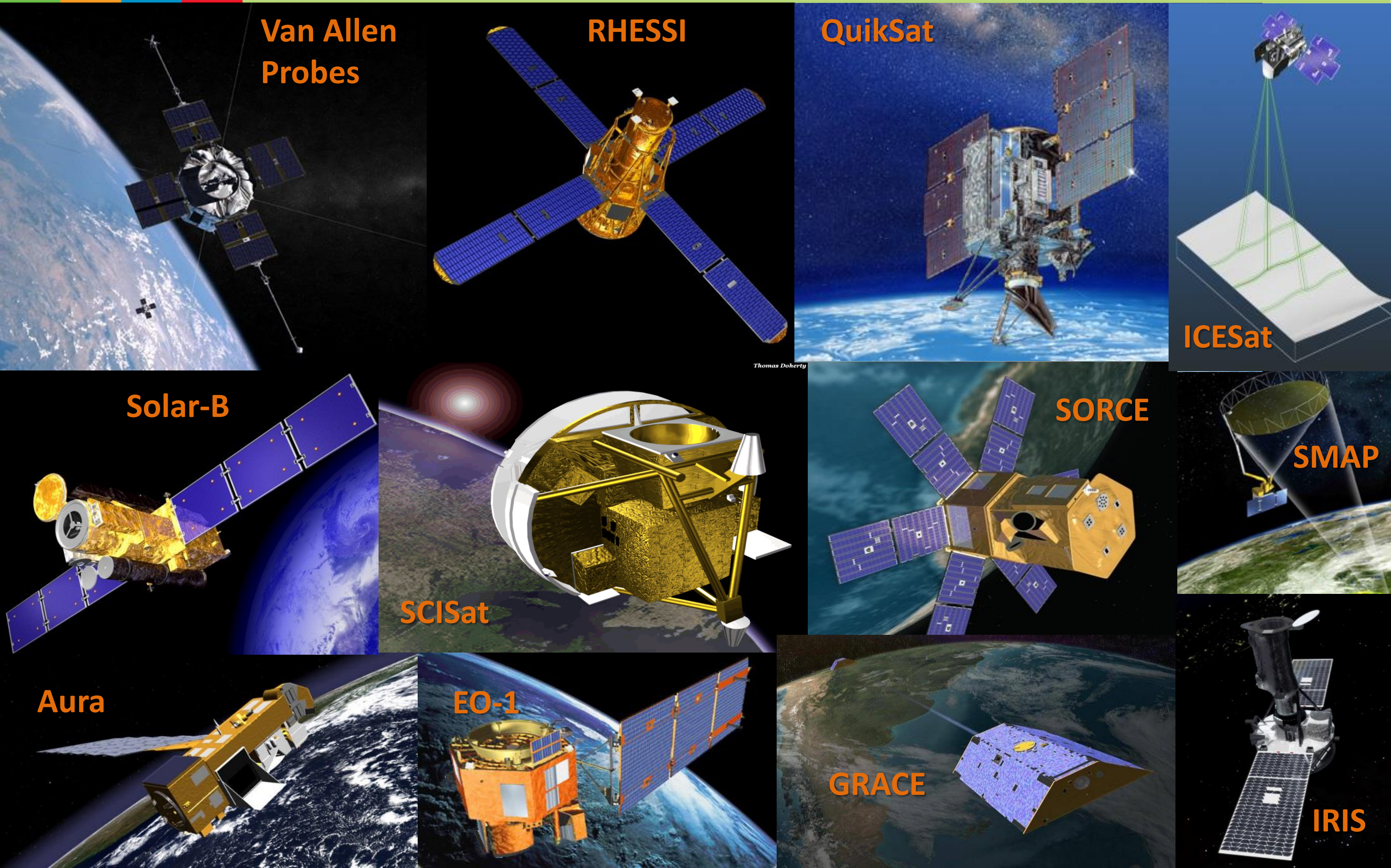
Commercial

- Dongara, Australia (Universal Space Network) (one 13 meter antenna)
- Hartebeesthoek, Africa (Satellite Application Center) (one 18 meter antenna)
- Kiruna, Sweden (Swedish Space Corporation – SSC) (two 13 meter antennas)
- North Pole, Alaska (Universal Space Network) (four antennas – 5.4, 7.3, 11, and 13 meter)
- Santiago, Chile (Swedish Space Corporation – SSC) (one 12 meter, one 13 meter antennas)
- Singapore, Malaysia (Kongsberg Satellite Services – KSAT) (one 9 meter antenna)
- South Point, Hawaii (Universal Space Network) (two 13 meter antennas)
- Svalbard, Norway (Kongsberg Satellite Services – KSAT) (two 11 meter, one 13 meter antennas)
- TrollSat, Antarctica (Kongsberg Satellite Services – KSAT) (one 7.3 meter antenna)
- Weilheim, Germany (Universal Space Network) (two 15 meter antennas)

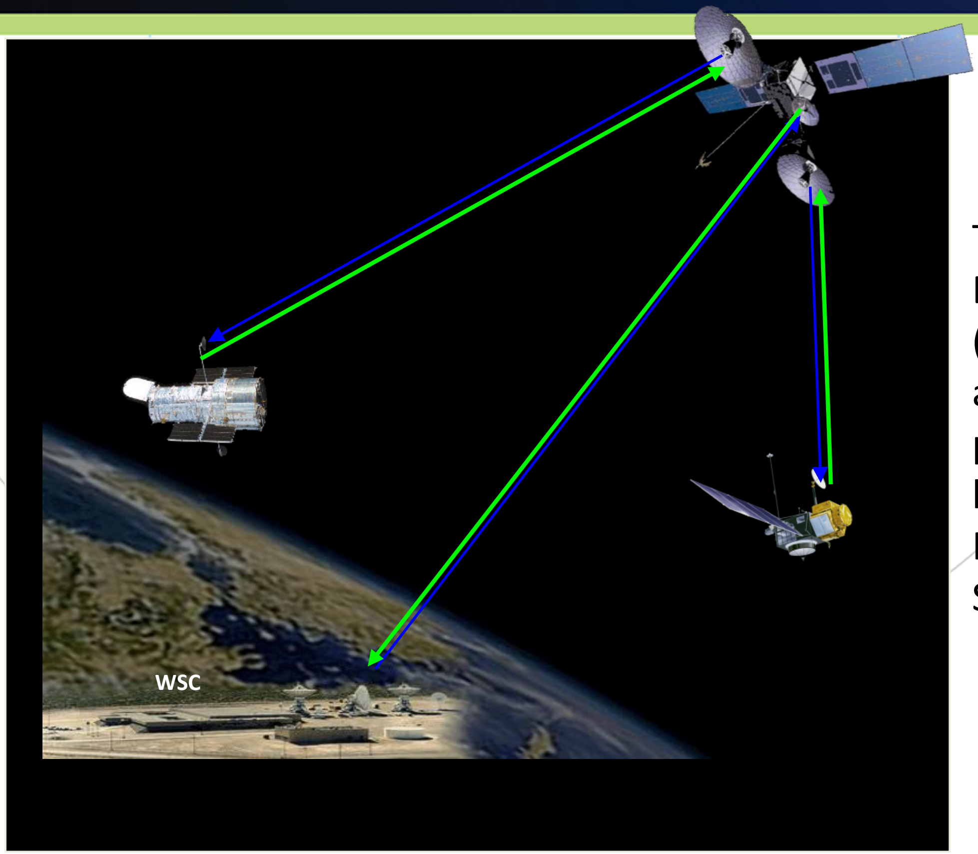
Partner

- Gilmore Creek, Alaska (National Oceanic and Atmospheric Administration – NOAA) (three 13 meter antennas)

Example: Near Earth Network Supported Missions



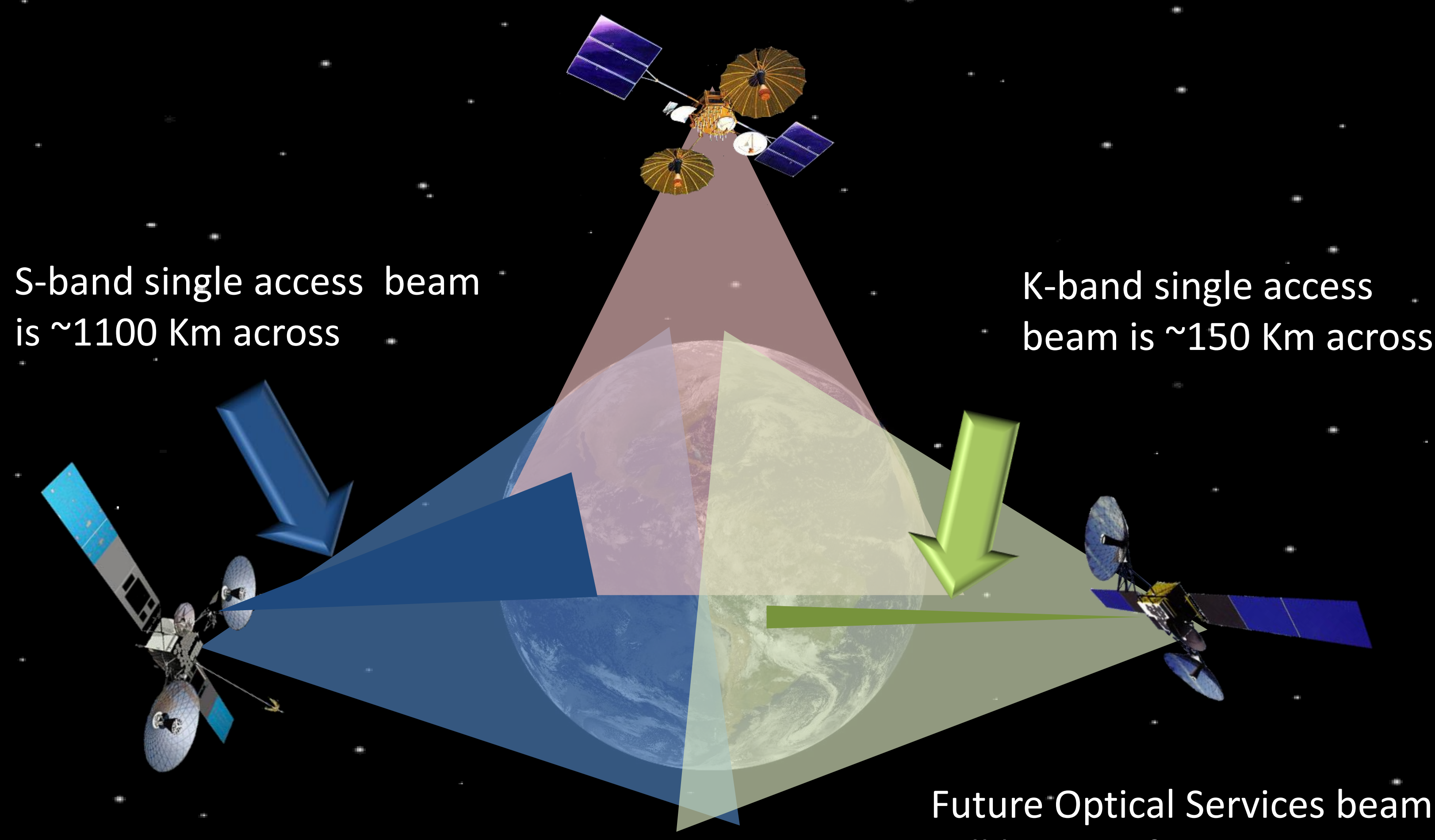
Space Network Concept



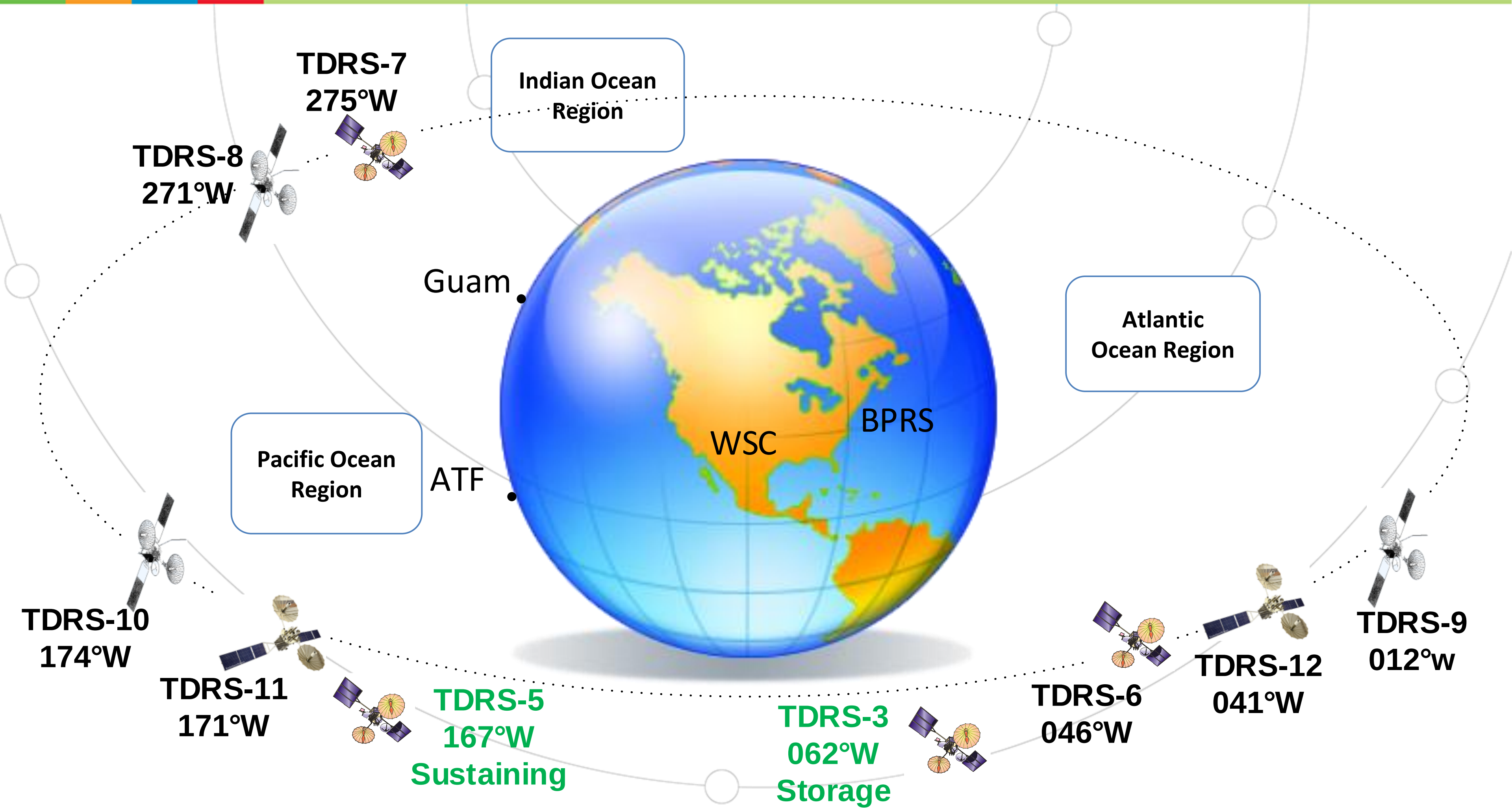
The Tracking and Data Relay Satellite (TDRS) provides an analog, radio relay platform which is located in space, thus It provides a Space Network (SN).

- Provide communications, data relay, and tracking services for Low Earth Orbiting (LEO) satellites, Human Space Flight, Space Shuttle, ISS, Expendable Launch Vehicles (ELV), and Scientific Customers.

Space Network Concept



Space Network: Tracking and Data Relay Satellite Fleet



Space Network: Ground Segment

White Sands Complex

Location: White Sands, NM

Antennas: three 19 meter, two 10 meter, five 4.5 meter, two 1 meter, three 18.3 meter

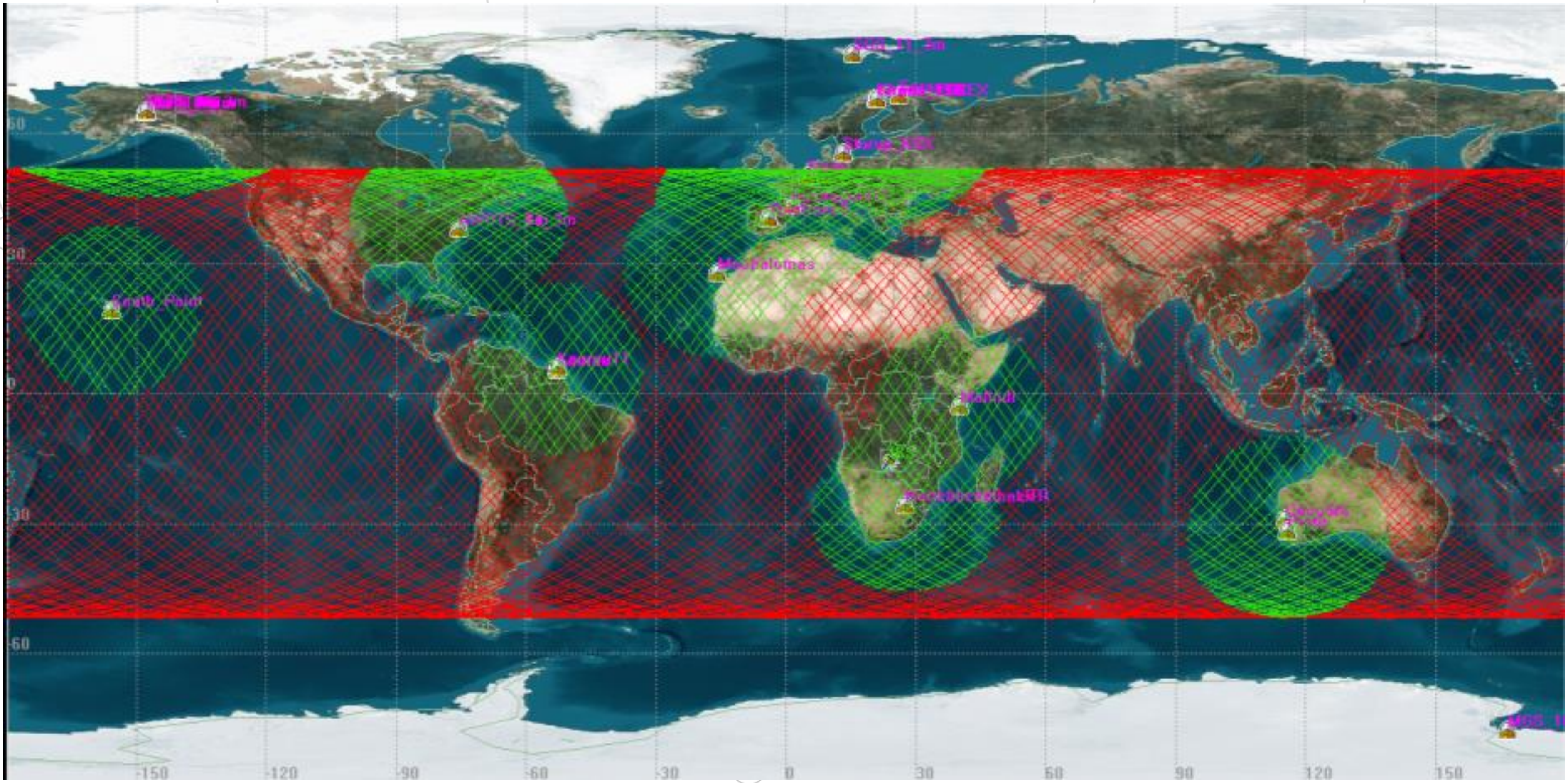
Guam Remote Station

Location: Guam Island

Antennas: one 11 meter, two 16.5 meter, one 4.5 meter, one 5 meter; backup in Dongara, Australia – one 11 meter

ISS Coverage is Limited without TDRS

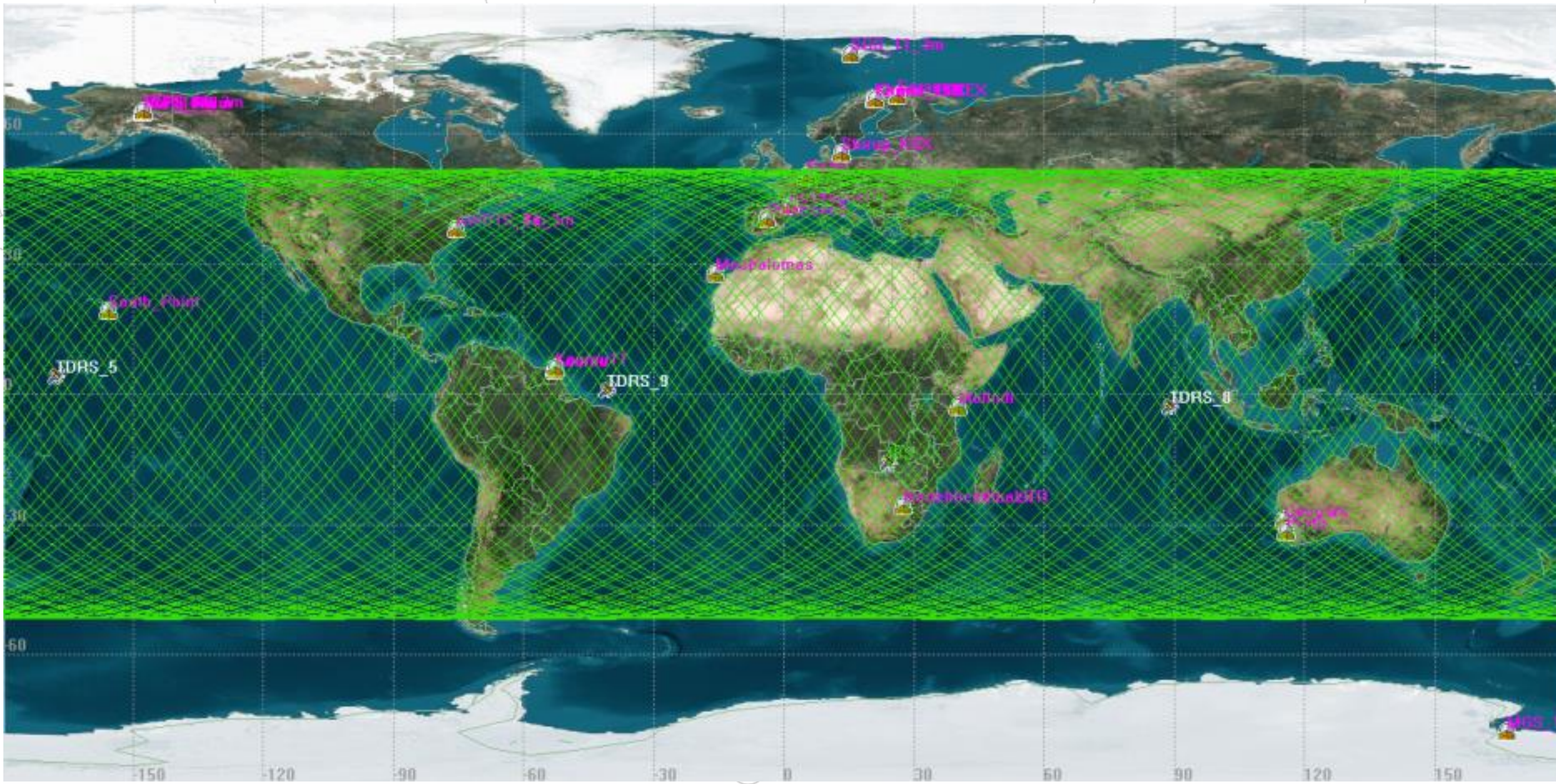
Typical ISS flight path coverage for 1 week without TDRS



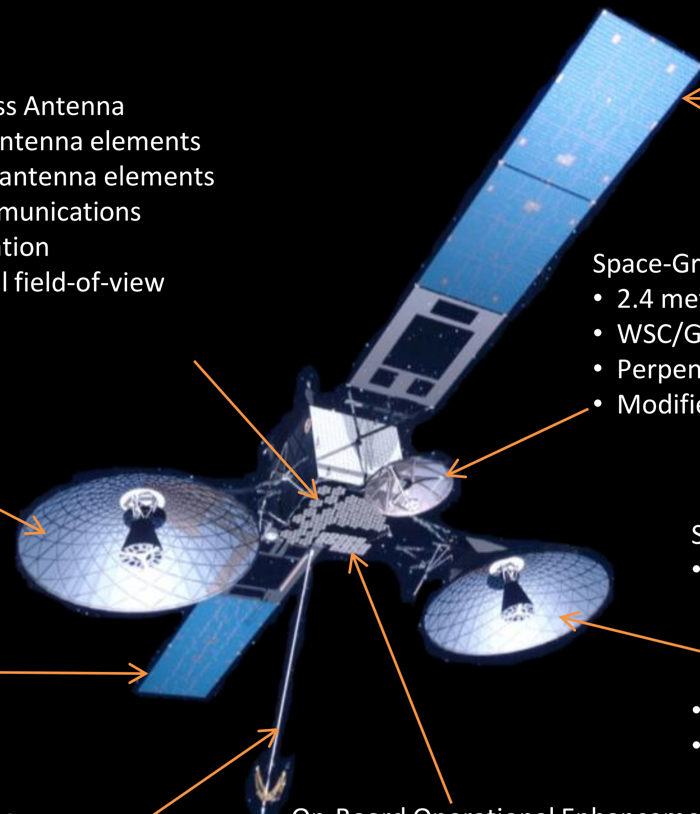
Tracks in green indicate possible ISS support from ground antennas
Tracks in red indicate unsupportable portions of flight path
Note: Does not meet human spaceflight (HSF) redundant comm requirements

ISS Coverage is 100% with TDRS

Typical ISS flight path coverage for 1 week using 3 TDRS’s



Space Segment:
Tracking and Data Relay Satellite (F8-F10)
Launched from 2000 to 2002



Multiple Access Antenna
- 32 receive antenna elements
- 15 transmit antenna elements
- S-band communications
- LHC polarization
- ± 13° conical field-of-view

Solar Panels

Space-Ground Link Antenna
- 2.4 meter Ku-band antenna
- WSC/GRGT-TDRS uplink/downlink
- Perpendicular, linear polarization
- Modified frequency plan allows collocation

Single Access Antenna

Single Access Antenna
- Tri-frequency communications
  - S-band
  - Ku-band
  - Ka-band
- Circular polarization (LHC or RHC)
- Up to 1.2 Gbps capability

Solar Panels

Omni Antenna
- S-band TT&C
- LHC polarization

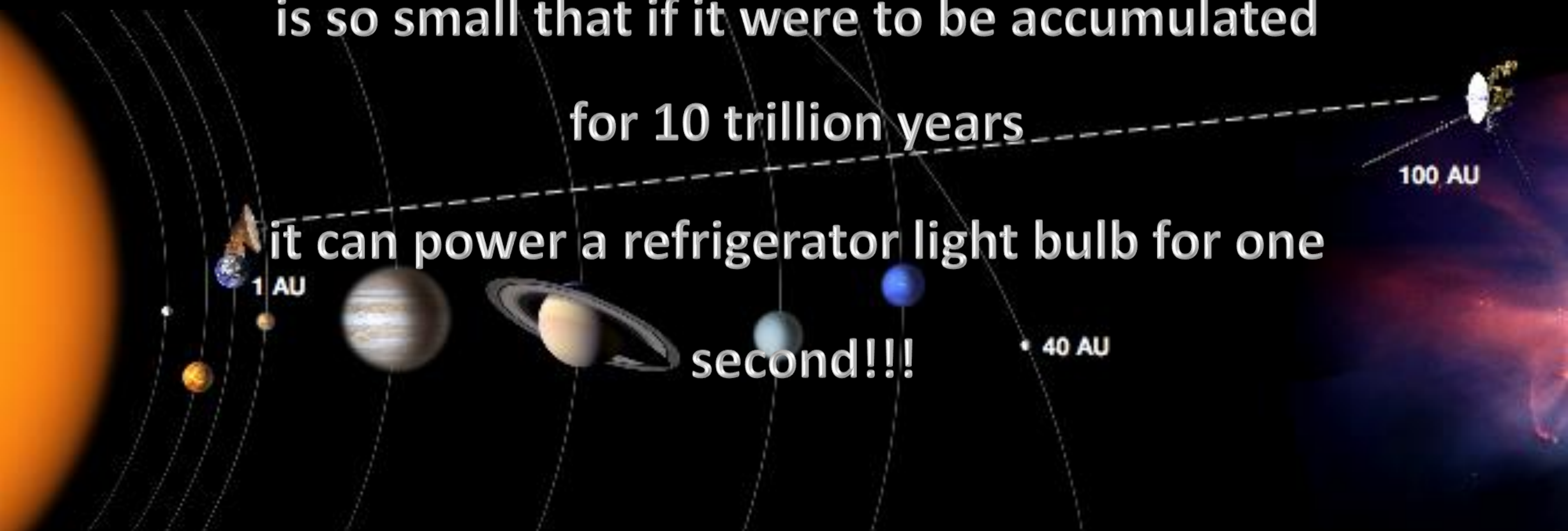
On-Board Operational Enhancements
- On-board SA antenna control
- Autonomous recovery from anomalies
- Improved monitoring

TDRS-K: Launched January 30, 2013
TDRS-L: Launched January 23, 2014

Example: Space Network Supported Missions

Deep Space Communications
The Ultimate Communications Challenge

The power received by the 70m DSN antenna from Voyager is so small that if it were to be accumulated for 10 trillion years it can power a refrigerator light bulb for one second!!!



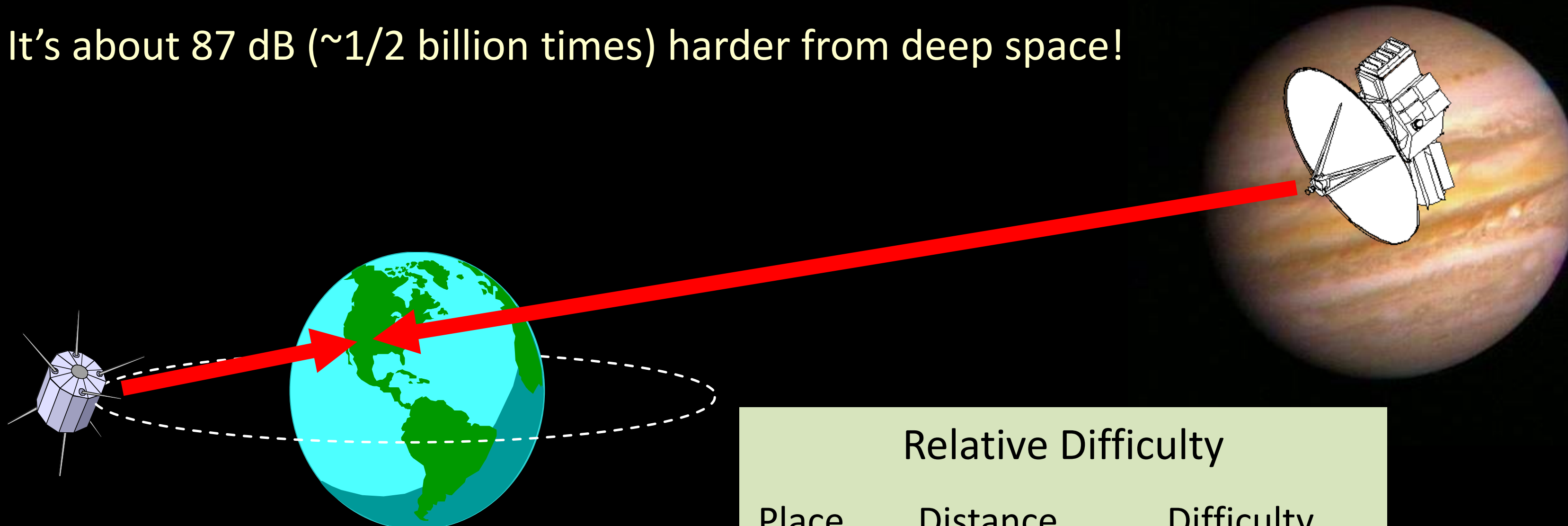
- **can you hear me now?**

Why is Deep Space Communications Difficult?

Communications performance decreases as the square of the distance.

Jupiter is nearly 1 *billion* km away, while a GEO Earth communications satellite is only about 40 *thousand* km away

– It's about 87 dB (~1/2 billion times) harder from deep space!



Relative Difficulty

Place	Distance	Difficulty
Geo	4×10^4 km	Baseline
Moon	4×10^5 km	100
Mars	3×10^8 km	5.6×10^7
Jupiter	8×10^8 km	4.0×10^8
Pluto	5×10^9 km	1.6×10^{10}

Deep Space Network (DSN)

Canberra Deep Space Communications Complex, Australia

Madrid Deep Space Communications Complex, Spain

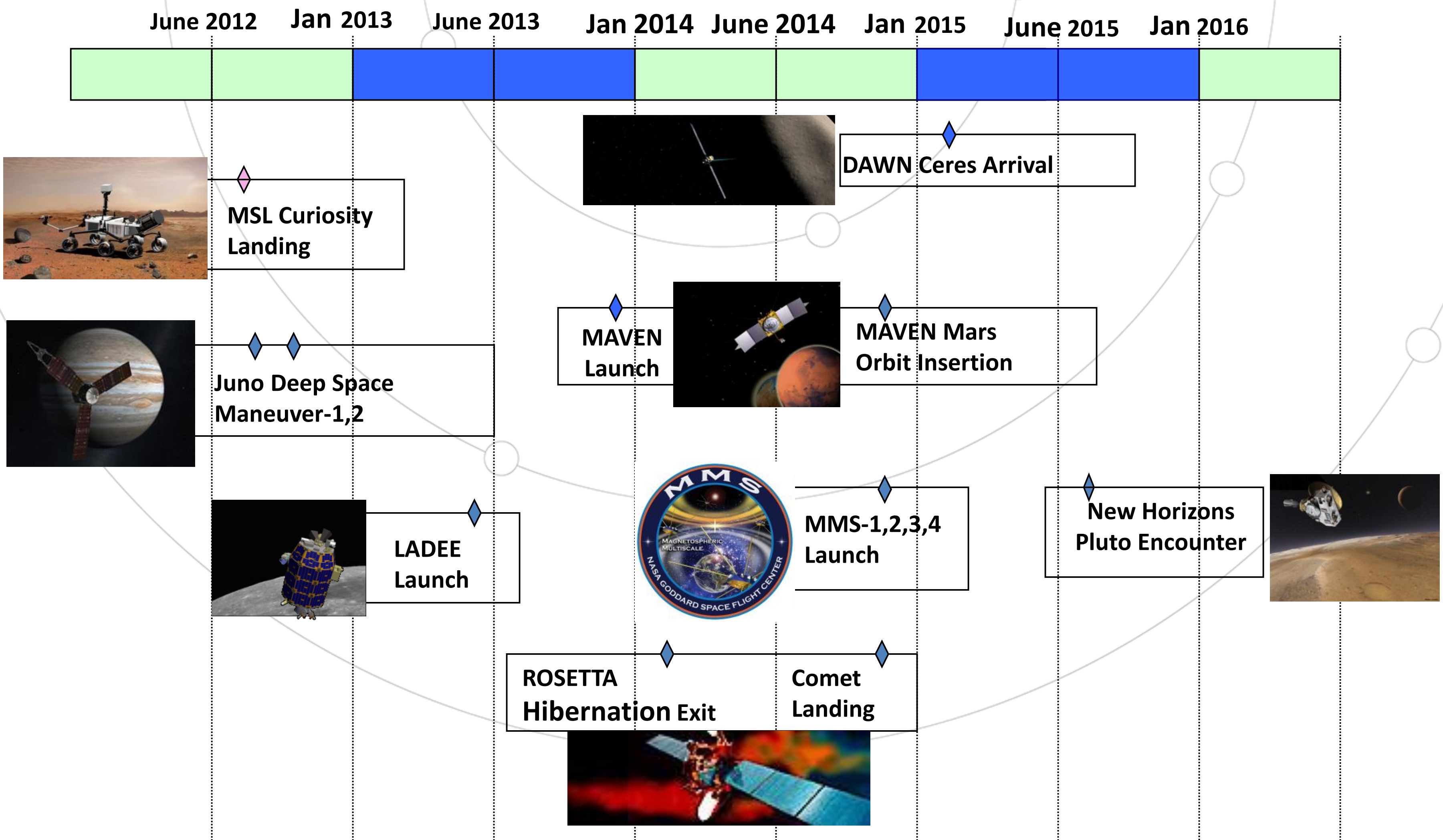
Goldstone Deep Space Communications Complex, California

NASA's Deep Space Network (DSN) was established in December 1963 to provide a communications infrastructure for all of NASA's robotic missions beyond Low Earth Orbit.

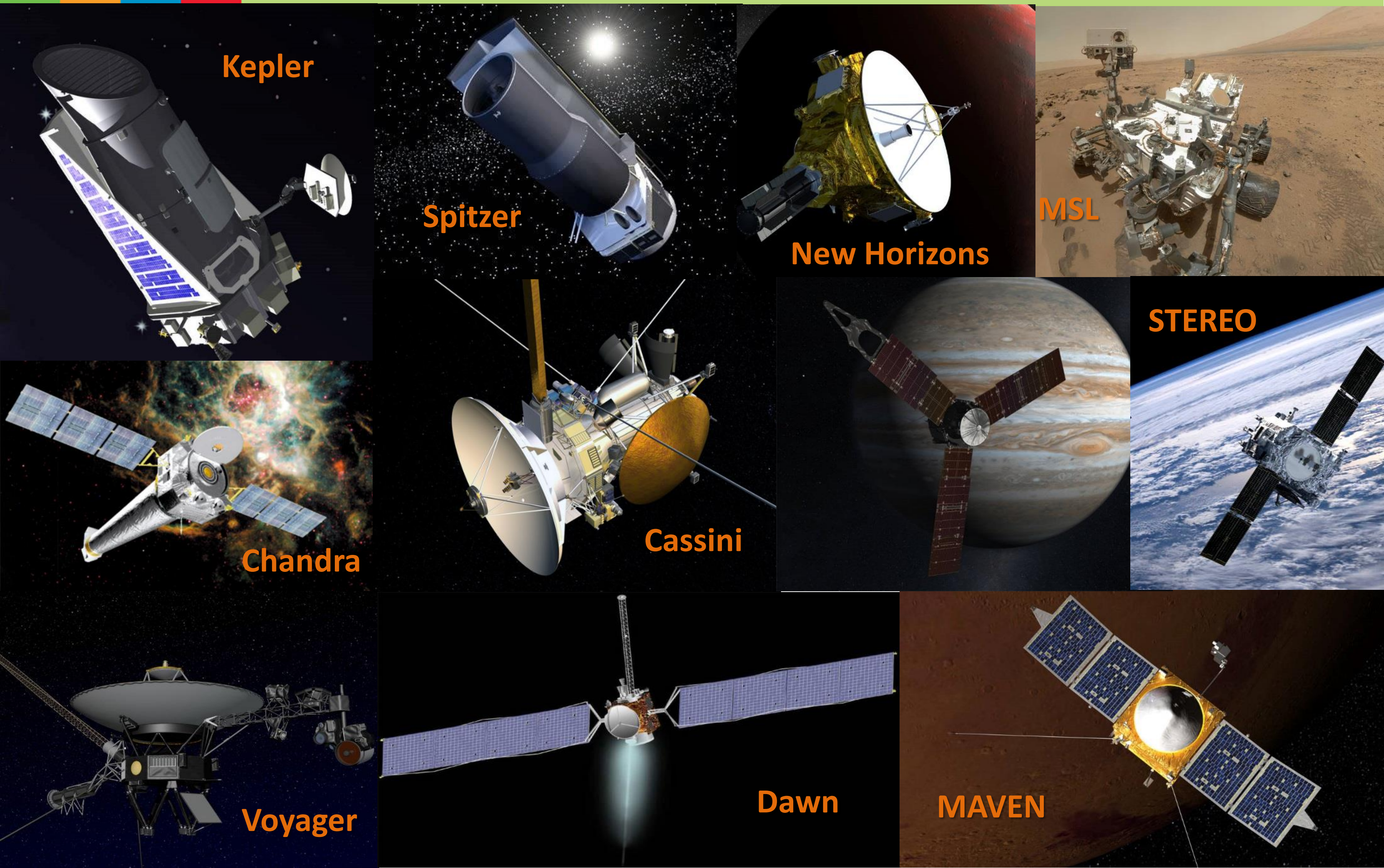
DSN 70 Meter Antennas

Deep Space Network 70 meter antennas are located in Canberra, Goldstone, and Madrid. Besides communications they provide Radio Science and Astronomy and Planetary Radar.

DSN Recent Mission Events Timeline

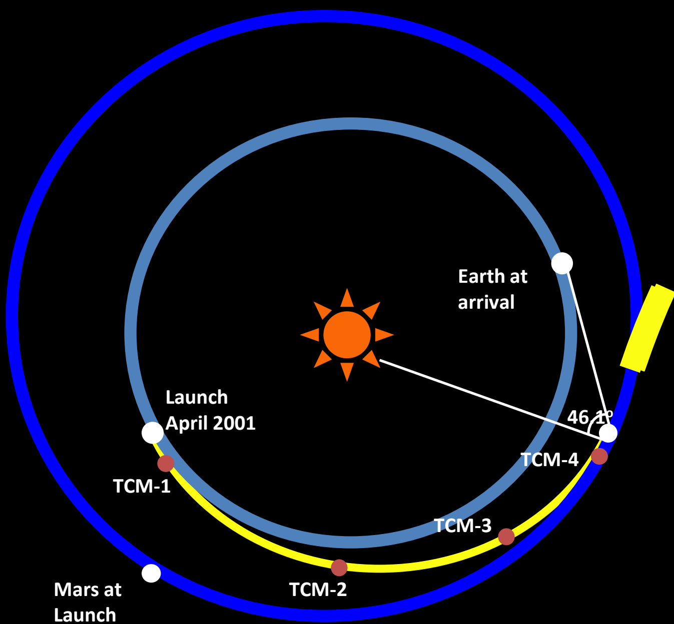


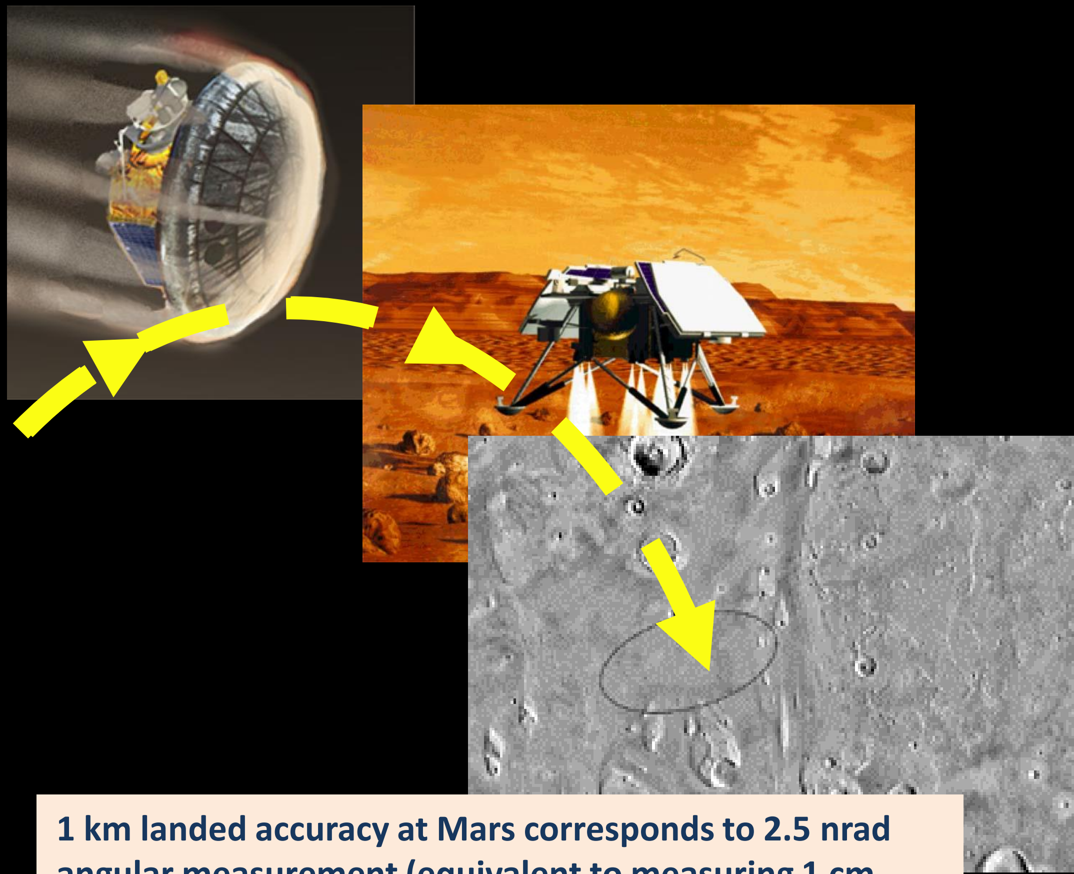
Example: Deep Space Network Supported Missions



Why is Deep Space Navigation Difficult?

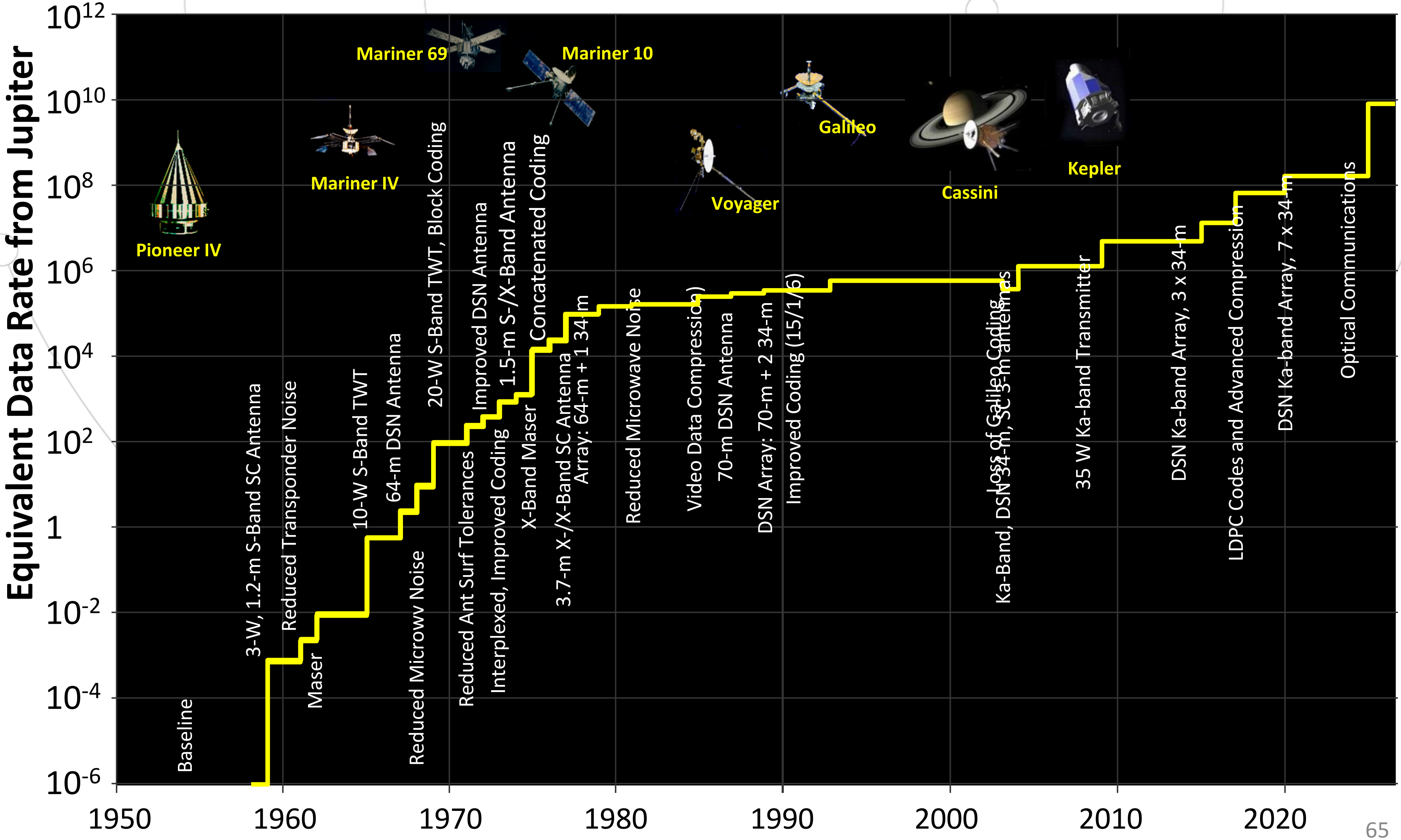
- Deep space missions use communication links to help with navigation
- Very accurate positions needed over very large distances
- Also must “navigate” the target bodies!



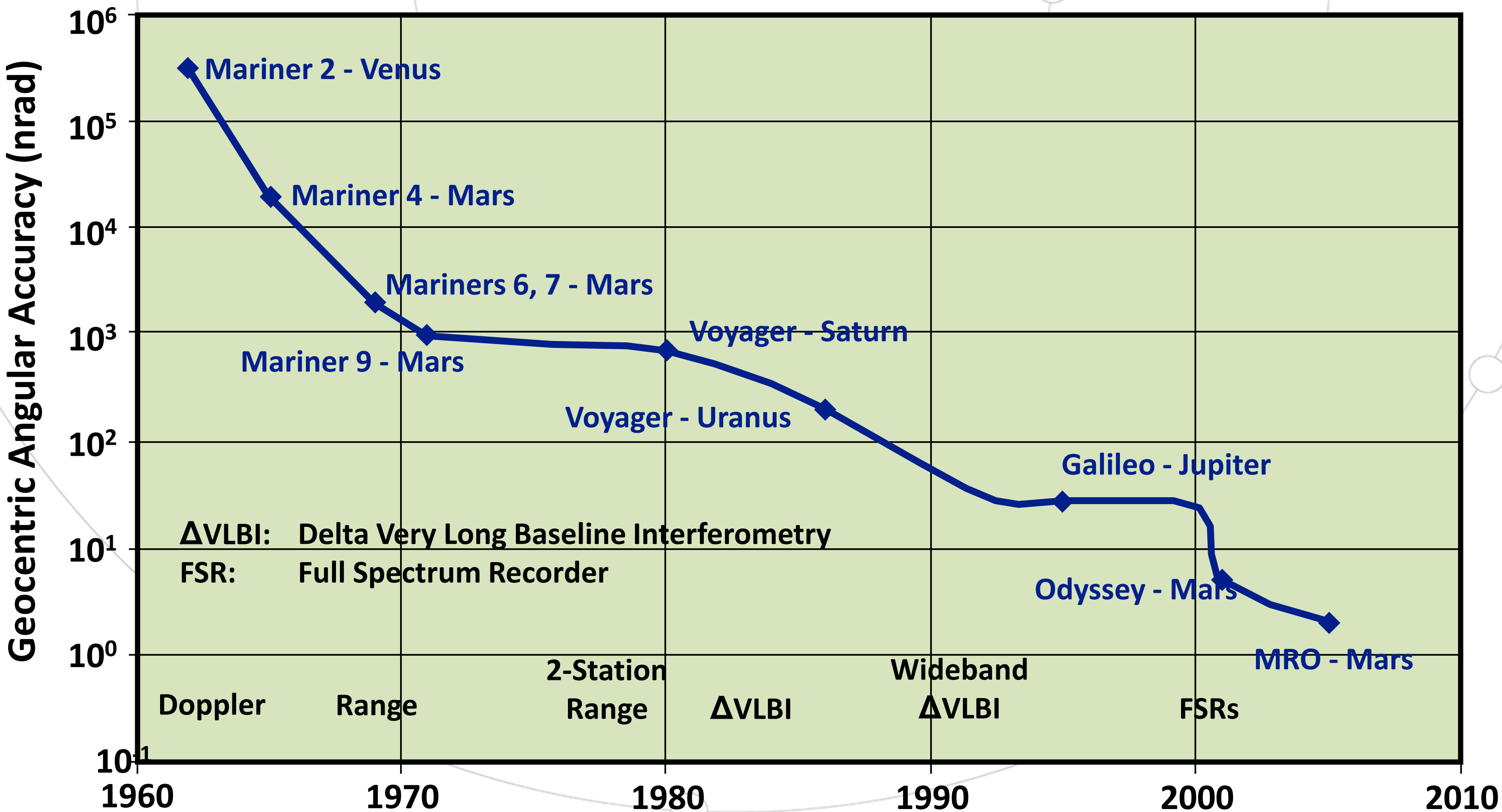


1 km landed accuracy at Mars corresponds to 2.5 nrad angular measurement (equivalent to measuring 1 cm items in Washington DC by observing from L.A.)

Deep Space Telemetry

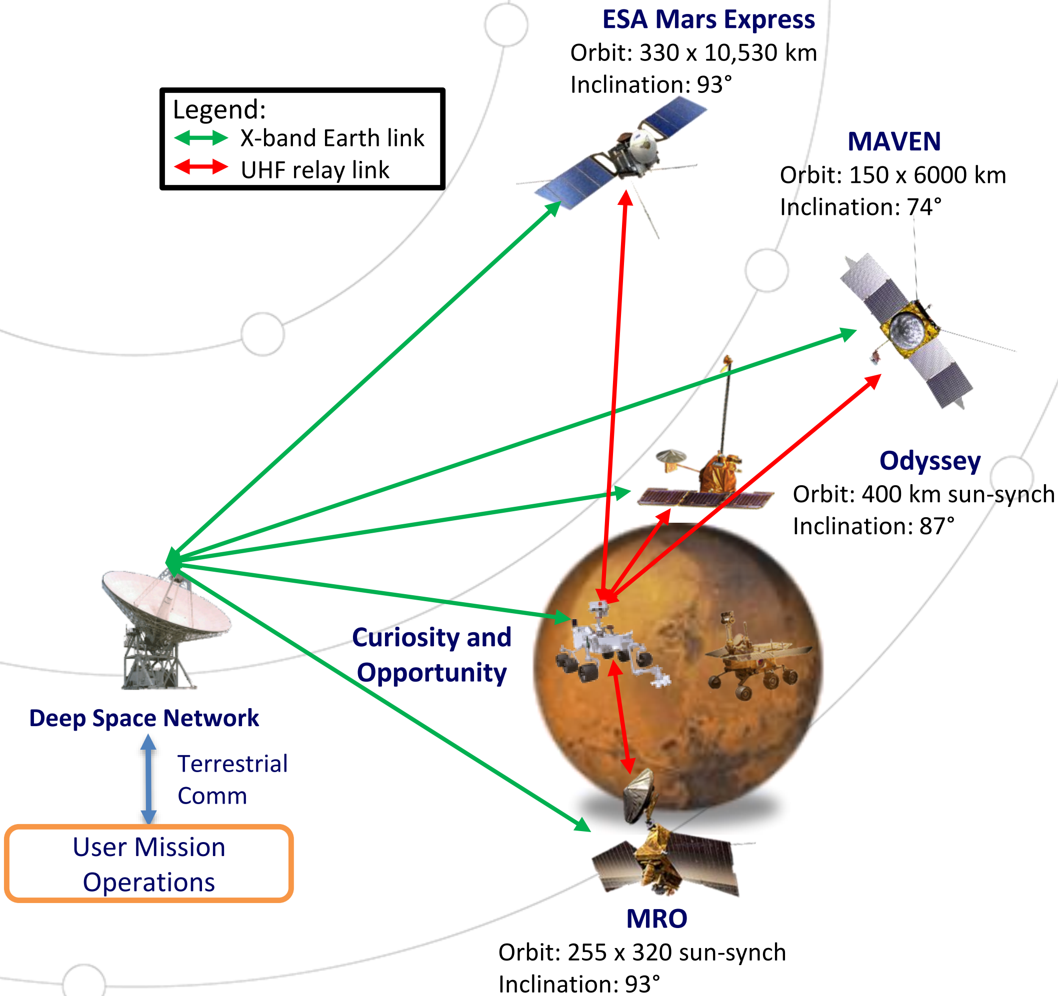


Deep Space Angular Tracking



Mars Network Today

- Evolving network of hybrid science/relay orbiters
  - Science-driven orbit selection
  - X-band links to DSN
- UHF proximity link with omnidirectional antennas
- Relay support to Opportunity and Curiosity
- Relay performance metrics
  - 1-2 contacts/sol
  - ~10 min per contact
  - ~450 Mb/sol average data return
  - 20 Mb/W-hour energy efficiency



Enabling International Collaboration

- SCaN represents NASA at international fora related to space communications and navigation issues. These include:

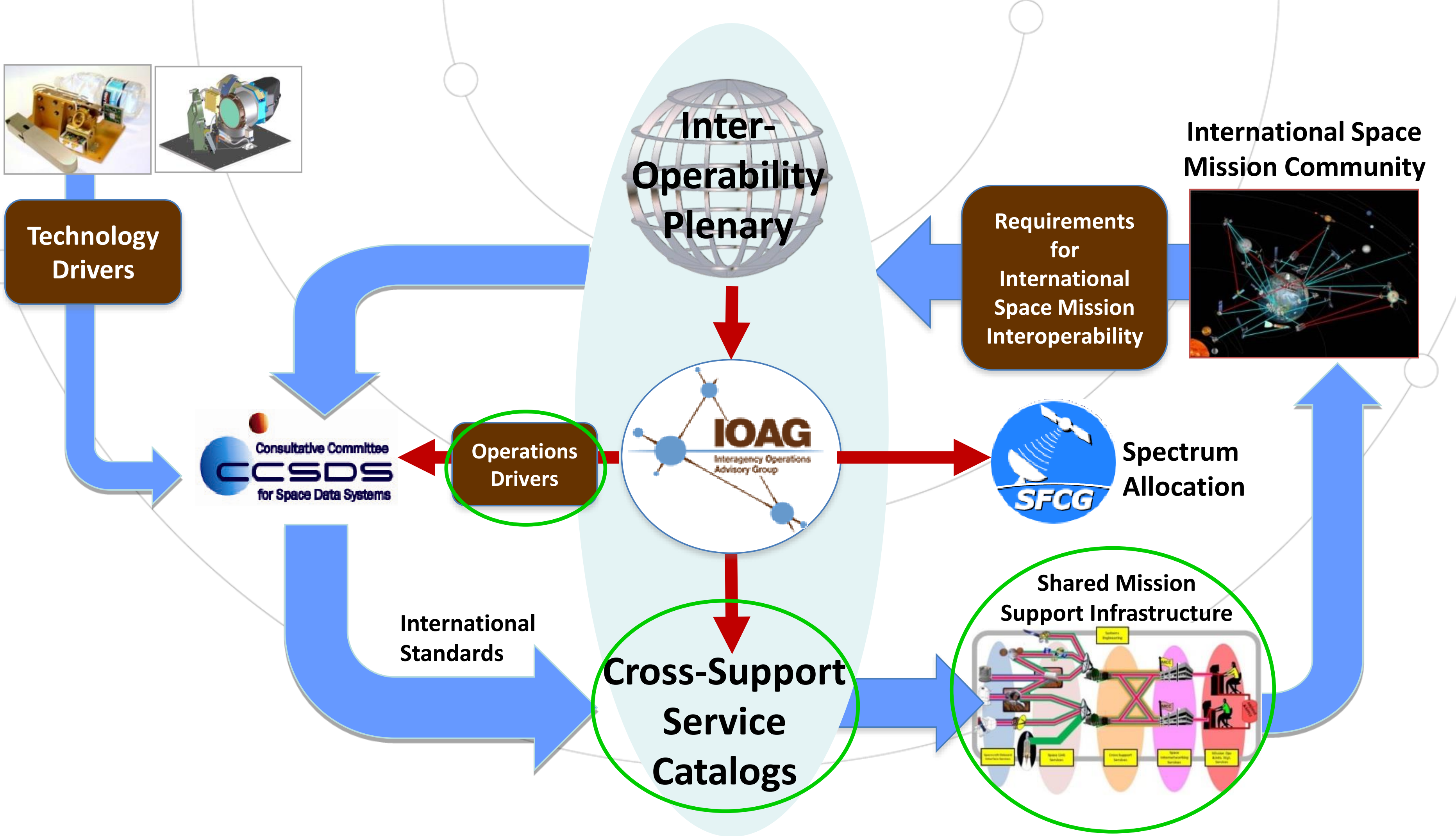
- Interoperability Plenary (IOP)
- Interagency Operations Advisory Group (IOAG)
- Space Frequency Coordination Group (SFCG)
- Consultative Committee for Space Data Systems (CCSDS)*
- International Telecommunications Union (ITU)
- International Committee on Global Navigation Satellite Systems (ICG)
- Bi-Laterals with other foreign space agencies
- International Committee on Space Operations (SpaceOps)*

* Brazil's Space Research Institute (INPE) is a member

Interoperability Plenary

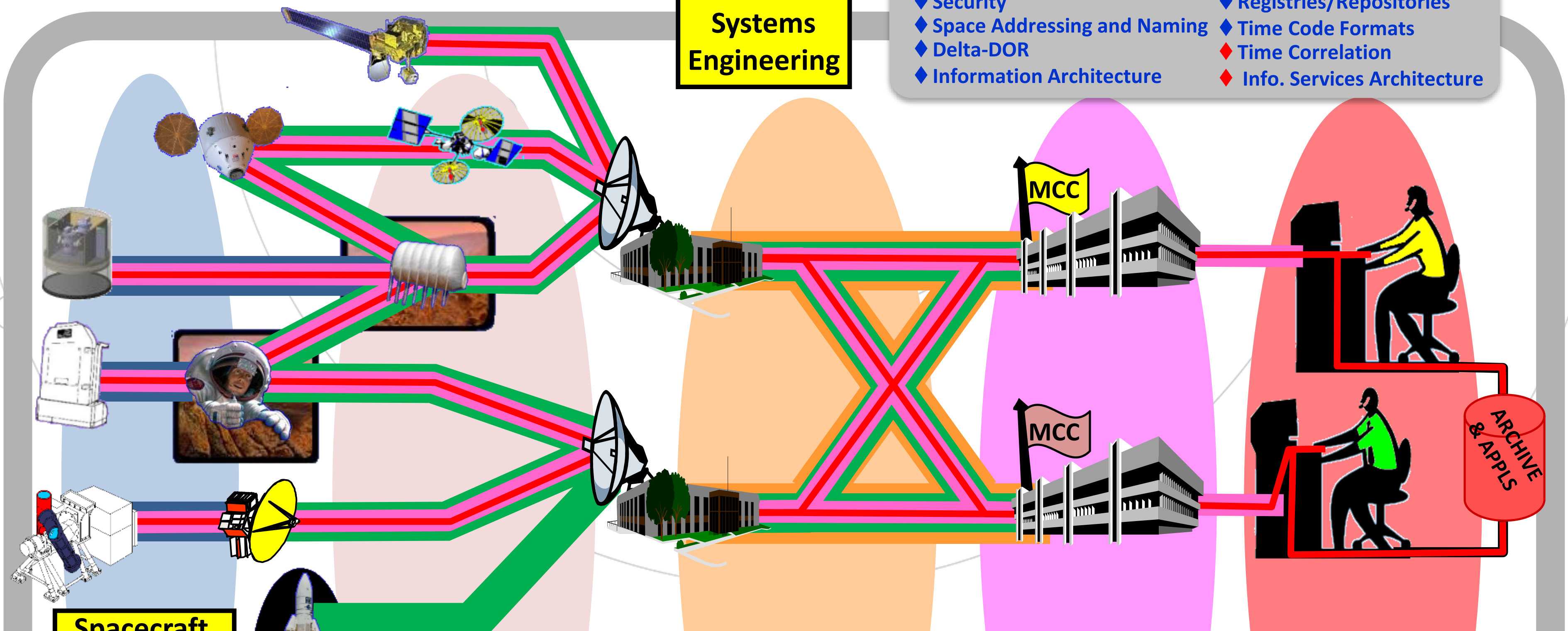
IOAG Interagency Operations Advisory Group

Roles of the IOP / IOAG / CCSDS / SFCG



End to End Architecture Standards Via CCSDS

- Systems Architecture
- Security
- Space Addressing and Naming
- Delta-DOR
- Information Architecture
- XML utilization
- Registries/Repositories
- Time Code Formats
- ♦ Time Correlation
- ♦ Info. Services Architecture



Spacecraft Onboard Interface Services

- Onboard Subnet. Services
- Onboard Application Services
- Wireless WG
- ♦ Plug-n-Play

Space Link Services

- RF & Modulation
- Space Link Coding & Sync.
- Multi/Hyper Data Compress.
- Space Link Protocols
- Ranging
- High Rate Uplink
- Space Link Security
- ♦ Planetary Surface Comm.
- ♦ Optical Modulation/Coding

Cross Support Services

- CS Service Management
- CS Transfer Services
- Cross Support Architecture
- ♦ CCSDS Reference Architecture

Space Internetworking Services

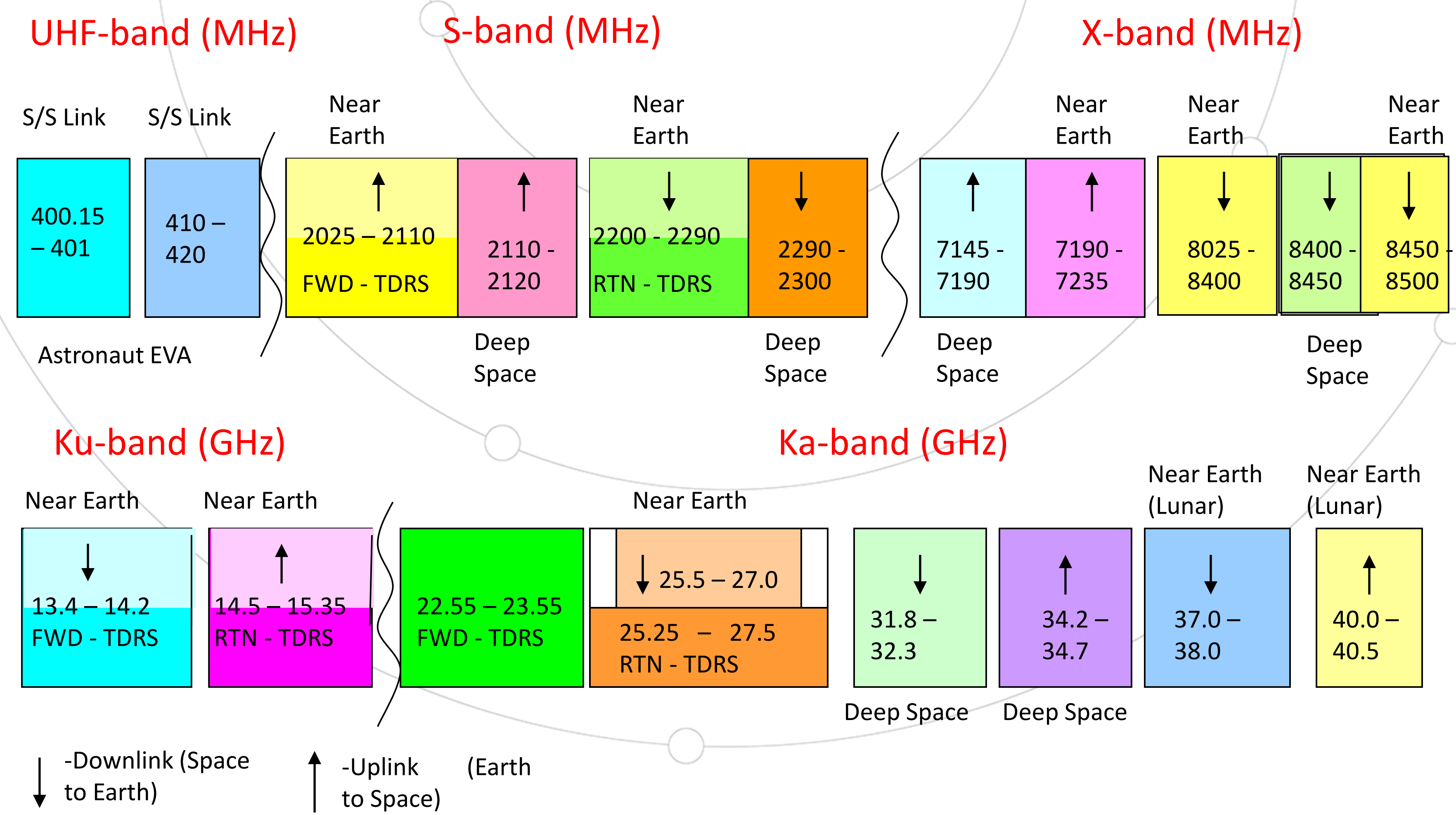
- Space Packet Protocol
- Asynch Messaging
- IP-over-CCSDS Links
- Motion Imagery & Apps
- Delay Tolerant Networking
- Voice

Mission Ops & Info. Mgt. Services

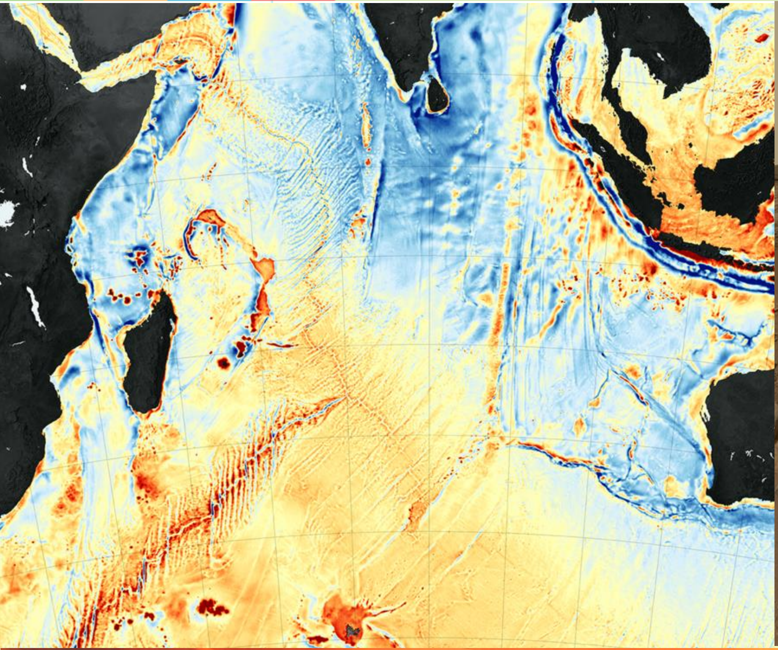
- Data Archive Ingestion
- Navigation
- Info. Pack. & Registries
- Spacecraft Monitor & Control
- Digital Repository Audit/Certification

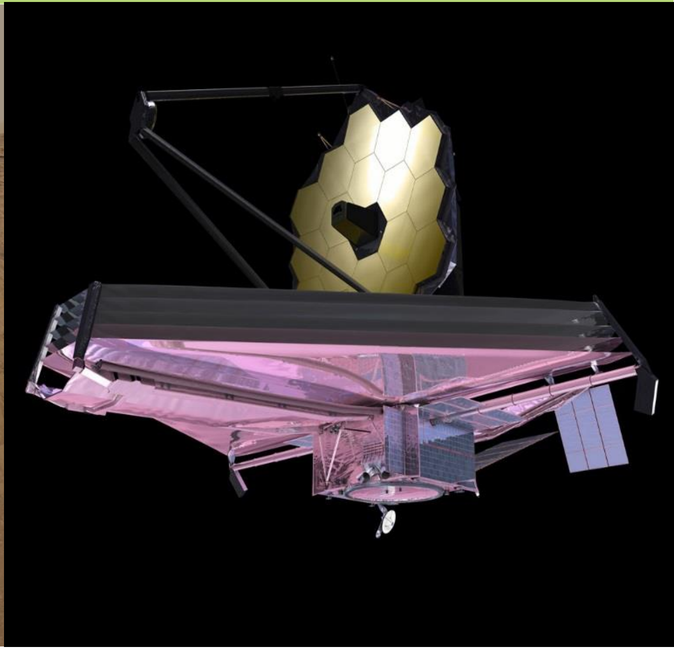
♦ = Studies

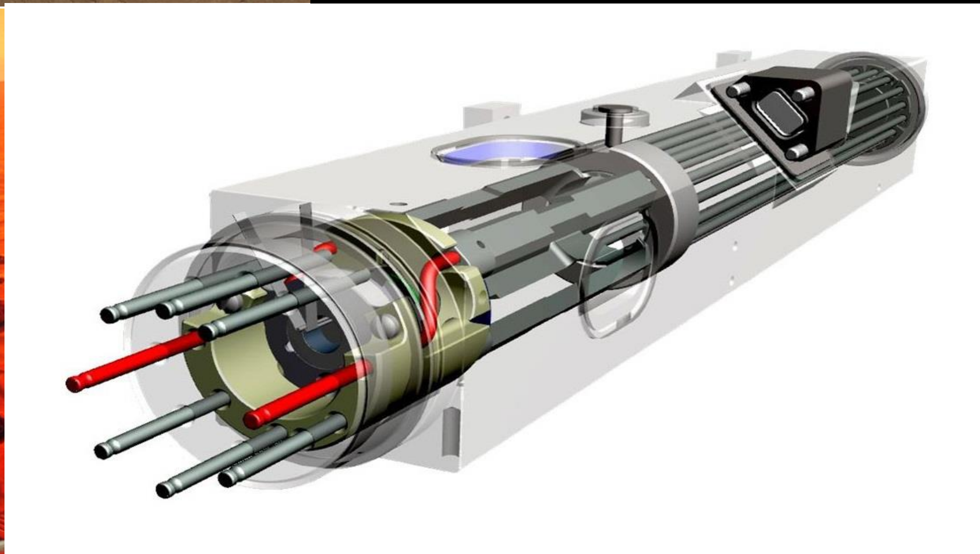
NASA's Most Frequently Used Bands for Communication



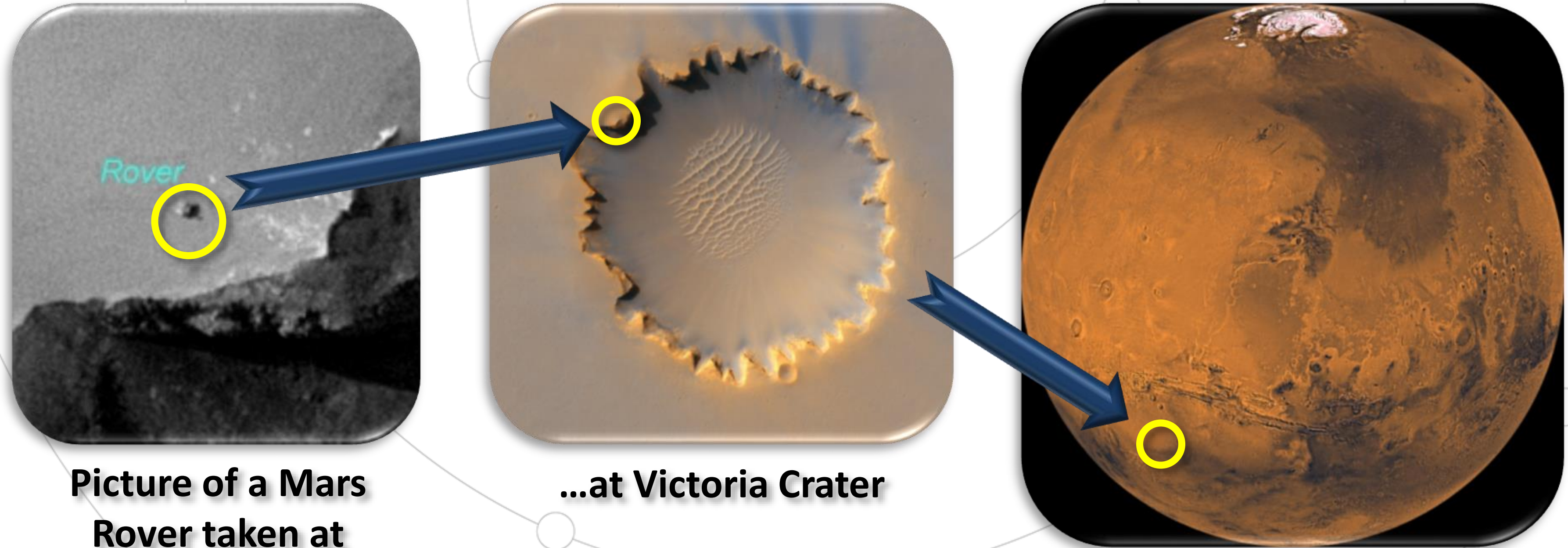
Future Missions







NASA needs more bandwidth to download more science from space….



Picture of a Mars Rover taken at one-foot resolution

…at Victoria Crater

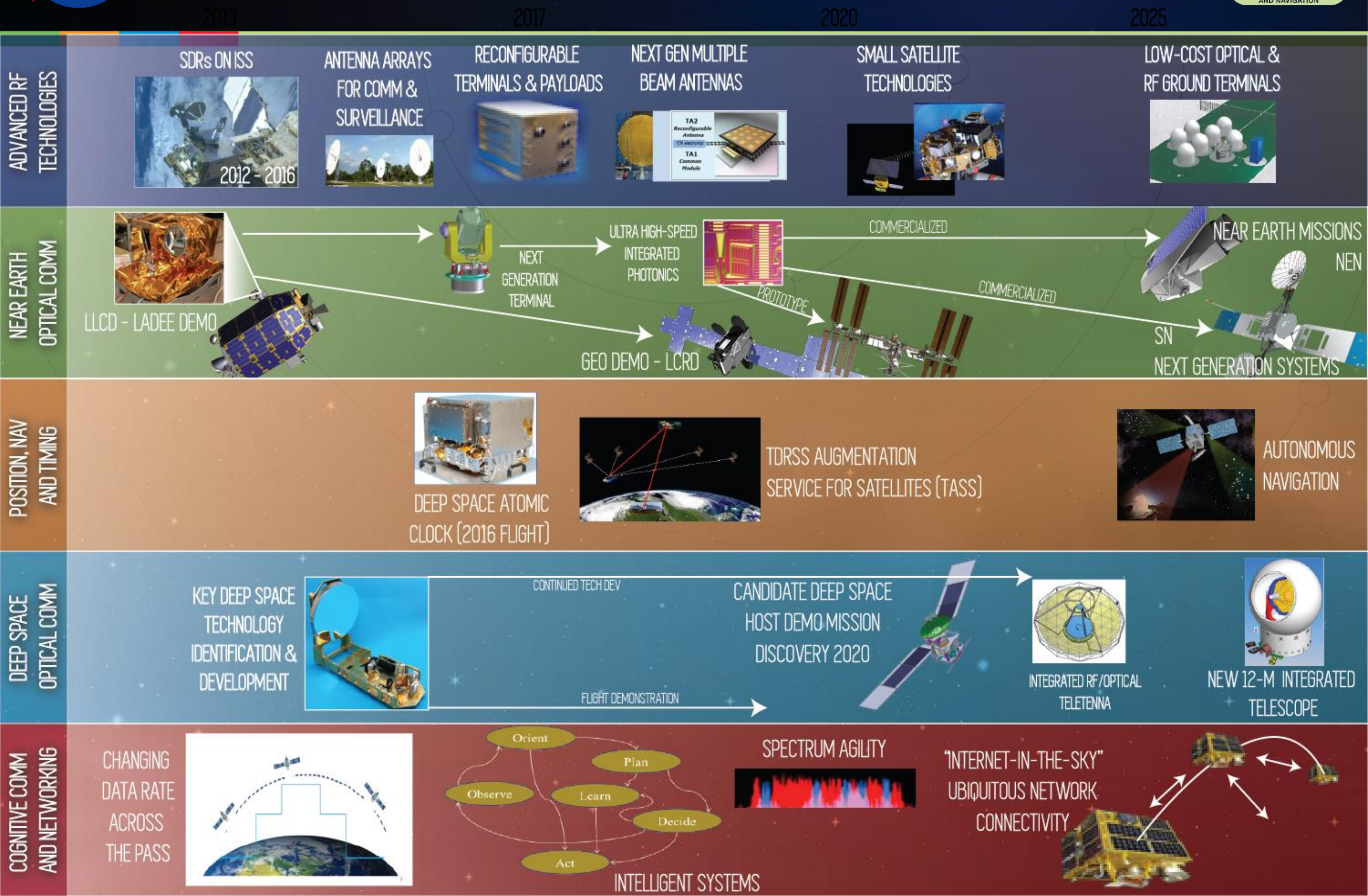
…on Mars

To transmit a 30 cm resolution "Google" map of the entire Martian surface (at 1 bit/pixel):

- Current RF (Ka-band) system would take 2 YEARS
- Laser communications can do it in 9 WEEKS!

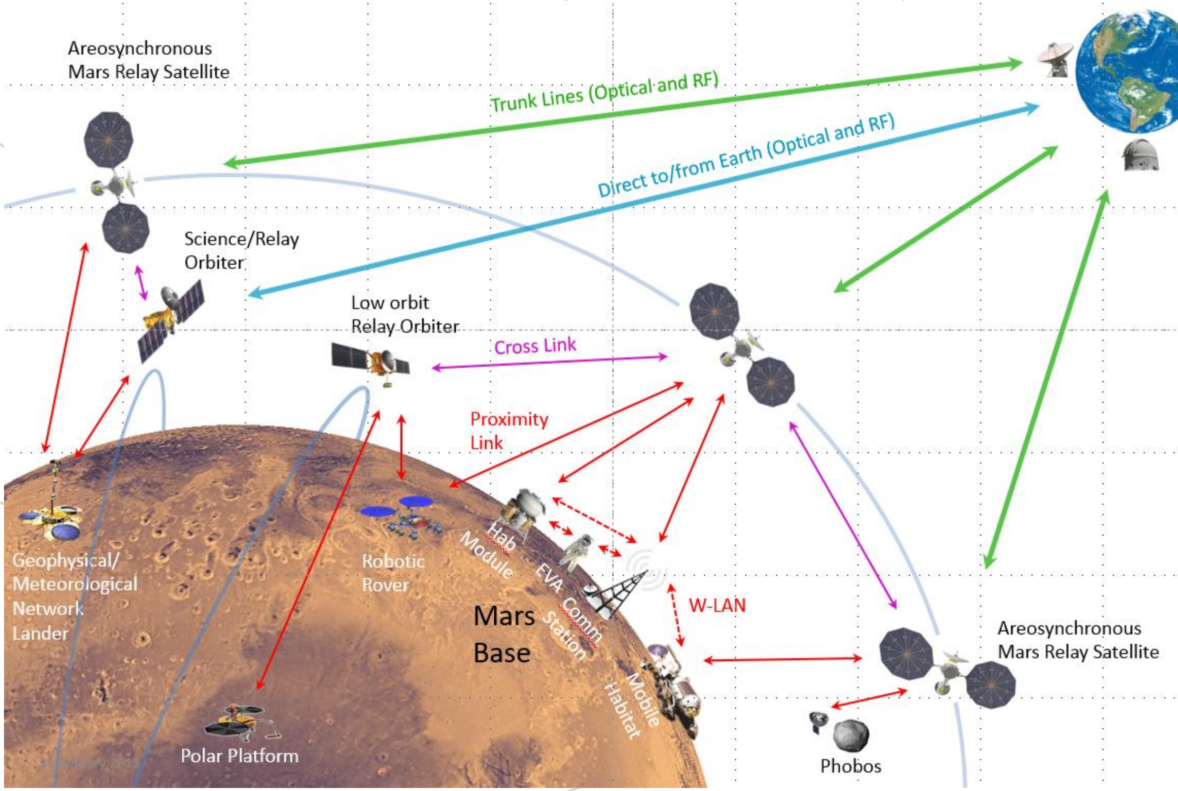
OPTICAL COMM'S HIGHER DATA RATES CAN BREAK THROUGH TODAY'S SCIENCE DATA BOTTLENECK

SCaN Technology Development and Infusion Roadmap



Future Mars Network Concept

- New/enhanced Services
  - Network layer service using DTN
  - Timing service
  - Celeslocation service: positioning service upgraded to provide GPS-like surface location
  - Inter-agency service management based on the CCSDS CSSM standard
  - Optimetric data & tracking services
  - SOA services: Application layer services such as look-up, directory, caching, storage, messaging, alarms/alerts
- Mars Network architecture
  - Network with dedicated relay orbiters in high Mars orbit (areosynchronous?) for full coverage and/or relay payloads on science orbiters
    - Coverage focused on Mars Base
    - Coverage includes Phobos & Deimos
  - Continuous trunk line availability to Earth for low end-to-end forward/return data latency
  - Deep Space Optical Capability (DSOC) terminals deployed on mission spacecraft, the dedicated relay orbiter, and surface elements
  - Relay orbiters support return trunk line at ~150 mega-bits per second (Mbps) (Ka-band) and ~300 Mbps (optical) as well as 50 Mbps for the forward trunk line
  - On Earth, deep space optical ground telescopes providing continuous optical support



Opportunities with NASA

International opportunities:

http://www.nasa.gov/offices/education/programs/descriptions/Students-rd.html

Opportunities for US citizens:

https://intern.nasa.gov/ossi/web/public/guest/searchOpps/

Opportunities Via the Agência Espacial Brasileira (AEB):

http://www.aeb.gov.br

STS-131: April 2010

However you decide to use your talents…

…keep dreaming and aim for the stars!

NASA
www.nasa.gov

NASA Space Communications and Navigation

https://www.nasa.gov/scan
Facebook: NASASCaN
Twitter: @NASASCaN